MACHINE AND FITTING SHOP PRACTICE

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MACHINE AND FITTING SHOP PRACTICE

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VOLUME II

PLANING, SHAPING, AND SLOTTING, DRILLING, BORING, AND REAMING; MILLING AND GEAR-WHEEL CUTTING; LATHE WORK; GRINDING AND LAPPING; SCREW-THREAD CUTTING; INTERCHANGEABLE SYSTEM OF MANUFACTURE

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PREFACE.

This book has been written especially for engineering-works' apprentices and engineering-college and technical-school students, for use in connection with the early stages of their practical work; hence the various subjects which are herein dealt with have been treated in a more or less rudimentary manner. At the same time, an attempt has been made to make the book as up-to-date as possible, and wherever it has been thought desirable the modern developments, especially in regard to machine-tool practice, have been indicated, so as to make the book as useful as possible to those who are interested in modern engineering-workshop practice.

Greater attention has been given in the book to principles and methods of working, processes, operations, tools, and instruments than to the actual machines in or on which the various descriptions of machine-shop work are carried out, this arrangement preventing confusion and enabling the Author to devote more space to the *minutiæ* that occur in the operation of the machines and in the use of the tools.

This is the second volume of the book, and as such deals almost exclusively with actual machine-tool operations and cutting-tools, special attention being given to the questions of tool angles and shapes and cutting speeds and feeds. All the ordinary machine-tool processes are dealt with, as well as the fundamental principles of the interchangeable system of manufacture.

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Sheffield University,
May, 1919.

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CHAPTER I

PLANER, SHAPER, AND SLOTTER PRACTICE

Planing Machine or Planer.—This machine is essentially one for the production of flat or plane surfaces by means of a single-edged cutting tool The general design of the machine is such that the work-piece has given to it a to-and-fro motion by means of a special mechanism in the machine, whilst during each active cutting stroke the cutting tool remains stationary, though during the whole operation the tool is moved across the work in a horizontal, vertical, or oblique direction according to the nature of the operation.

The fundamental principle of action of this machine is indicated graphically in Fig. 1, in which the full and dotted arrows W in the upper view represent the two movements of the work-piece, whilst the full arrow T in the lower plan view represents the cross or transverse movement of the tool or tools.

The essential parts of the ordinary form of this machine are a cast-iron bed of substantial proportions, two sides or housings, which are secured rigidly to the bed; a table or platen, which has a to-and-fro motion communicated to it, and which carries the work-pieces; a top-rail, which holds the

two housings at the top, a cross-rail, which is capable of being moved upwards and downwards in front of the housings, and which can also be secured to them rigidly whenever necessary, a saddle, which is carried on the cross-rail, a head, which is mounted on the saddle, and a tool box or holder, which is secured to the head. On the side of the table stroke dogs, tappets, or stops are used, the

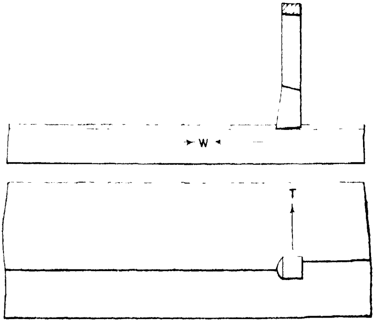

FIG. 1.—Diagram illustrating principle of operation of planing machine.

function of these being to fix the end of each stroke (that is, the forward and the backward stroke), and to cause the reversal of the direction of motion of the table at the right instant. By means of mechanism which is an intrinsic part of the machine, the tool can be fed along the cross-rail by power.

The table moves on square ways or in veed guides, the lubrication of these being more or less automatic in many cases. The table drive is usu-

ally either that of the screw and nut or that of the rack and pinion, the former enabling work surfaces free from chatter marks to be produced. In some few cases a crank is employed in the driving mechanism. In the top of the table are tee-slots, plain slots, and holes for use in connection with the clamping and holding of work-pieces.

The plate-edge planer is different from the ordinary form of planer, inasmuch as the work-pieces (usually large plates) are held stationary, and the tools are reciprocated in front of them.

Shaping Machine or Shaper.—This, generally, is a much lighter and smaller machine than the planer, and is distinguished from it by the fact that, in this machine, the work is held stationary, except for the cross-feed, and the tool is moved to-and-fro. The tool is carried in a tool box or holder mounted on the end of a slider or ram, the motion of which is horizontal and is obtained through the medium of a mechanism which works on the principle of either the rack and pinion or crank and vibrating rod. The motion of the tool is always horizontal. The work-pieces are mounted on a knee which is capable of being traversed horizontally (at right angles to the motion of the tool) and vertically. The knee is usually box-like in shape so that work-pieces can be secured to its side faces, as well as to its upper face.

In Fig. 2 is illustrated the fundamental principle of action of this machine, the dotted and full arrows T in the upper view representing the reciprocating motion of the tool, whilst the full arrow W in the lower plan view indicates the cross or transverse movement of the work-piece. A comparison of

Figs. 1 and 2 will clearly demonstrate the essential difference between a planing machine and a shaping machine.

Slotting Machine or Slotter. In this machine, the tool is held in a tool-box which is secured to a slider or ram having a vertical motion. This motion is generally communicated to the ram by means of crank and connecting-rod mechanism, so designed

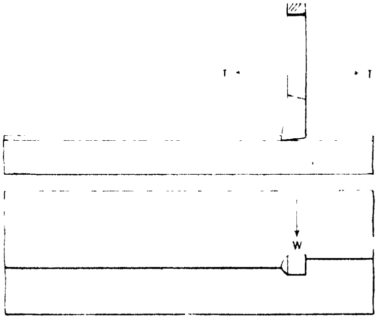

FIG. 2.—Diagram illustrating principle of operation of shaping machine

that the stroke of the tool can be readily altered, and that the actual positions of the two ends of the strokes of the tool can be varied without altering their relation. The table in this case is usually a circular one, and arranged so that it can be rotated in either direction or moved in a straight line in two horizontal directions at right angles to each other.

The fundamental principle of action of this machine is indicated in Fig. 3, in which the full

and dotted arrows T (the former for the cutting stroke, and the latter for the return stroke) represent the to-and-fro motion of the tool, and the full arrows W in the two plan views the motions of work-pieces having uni-directional straight line and circular motions respectively.

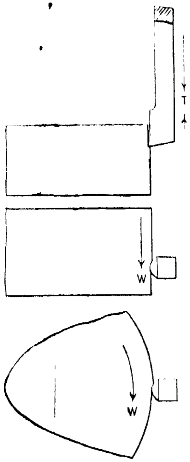

FIG. 3.—Diagram illustrating principle of operation of slotting machine.

The key-seating machine works on practically the same principle as the slotting machine, but its sphere of usefulness is not quite so extensive.

The so-called vertical shaping machine works on the same principle as the slotting machine.

Cutting Tools.—As with cutting tools used on

other machine tools, the efficiency of the cutting tools employed on these machines depends to a very large extent upon the shapes to which they are ground and the manner in which they are presented to the work-pieces.

Angles of Cutting Tools.—In dealing with the

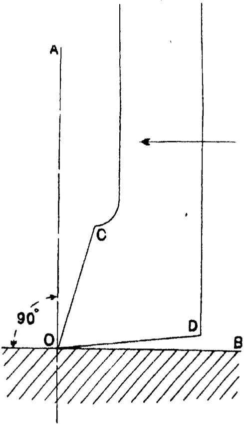

FIG. 4.—Angles of a planer or shaper tool.

question of the operation of these machines, it is necessary to have clearly before us the identification of certain well-defined angles of the tools. These angles apply to the noses of the tools, that is, the actual cutting parts of the tools, and the magnitudes and relations of these angles determine largely the manner and efficiency of cutting.

represented; in Fig. 5, that of slotter tools. In each case the line BO represents the surface of the work-piece, with O as the point of the tool. OA is normal to this surface. D is known as the *heel* of the tool, and the surface represented by the line OC as the *lip* of the tool. The lip of the tool may be

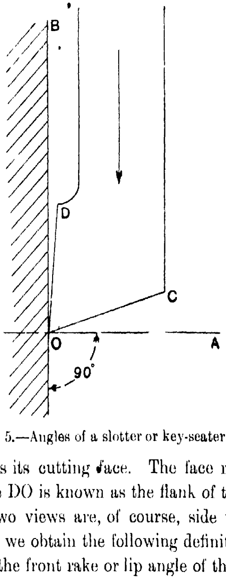

FIG. 5.—Angles of a slotter or key-seater tool.

regarded as its cutting face. The face represented by the line DO is known as the flank of the tool.

These two views are, of course, side views, and from them we obtain the following definitions:—

AOC is the front rake or lip angle of the tool.

BOD is the front or heel clearance or relief.

COD is the front tool angle.

COB is the front cutting angle.

At right angles to this plane there is another set of angles which correspond with these, the two sets being distinguished from one another by the use of the words *front* and *side*.

Shapes of Cutting Tools.—If a cutting tool is ground so that it has no front rake, its action is very imperfect and unsatisfactory, as is indicated in Fig. 6, from which it will be seen that the metal is crowded off from the work-piece. In this case, the

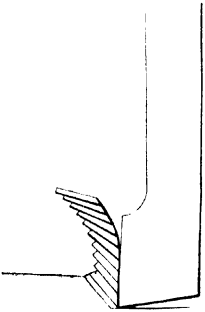

Fig. 6.—Cutting action of planer tool without rake.

action is in the nature of a push and is very different from the action which occurs when the tool is provided with front rake, as is shown in Fig. 7. The amount of front rake most suitable depends upon the metal to be machined, and the following angles of front rake have been found to give satisfactory results on planer and shaper tools: On brass, 0° to 5°; on cast steel, 5° to 15°; on cast iron, 10° to 20°; on mild steel and wrought iron, 15° to 20°

The function of side rake is to deflect the chip sideways over the part of the work-piece already machined, so as to prevent clogging-up of the tool. The angles of side rake are generally somewhat less than those of front rake.

The clearance or relief of these tools need not be greater than 5°, and may, in many cases, be no

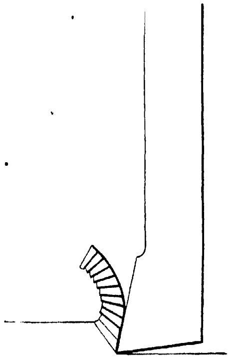

FIG. 7.—Cutting action of planer tool with rake.

greater than 3°. By keeping down the clearance angles, the tool angles (both front and side) are made large, and the nose of the tool is not made unduly weak.

The shapes of the noses of cutting tools used on these machines vary largely, depending, as they do, upon the nature of the operation to be performed in each case. For roughing work, the round nose or some modification of it, as indicated in Fig. 8 is

generally adopted. The diamond point (A, Fig. 9), square-nose (B), and the knife tool (C), are also used on the planer and shaper.

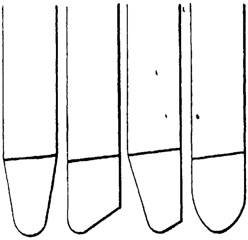

FIG. 8.—Forms of round-nosed tools.

The shape of the slotting tool is generally square, with or without the corners rounded off, though a cutting edge which is not quite straight, but ground

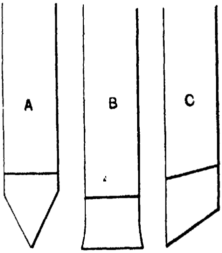

FIG. 9.—Shapes of planer tools.

to a fairly large radius, is probably more durable than a straight one. For special purposes, special shapes are sometimes employed, but these are the exception rather than the rule.

A tool holder designed for use in planing machines is illustrated in Fig. 10. The holder

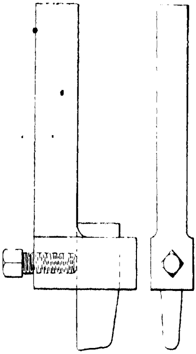

FIG. 10.—Tool holder.

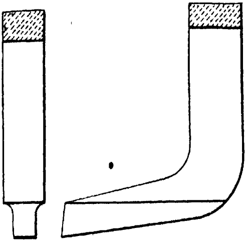

FIG. 11.—Keyway-cutting tool.

itself is made of forged steel of a quality much inferior to high-speed tool-steel, of which the cutting element is made. It can be used in connection

with heavy cutting with as much satisfaction as can a solid tool.

In Fig. 11 is shown a solid shaper tool for

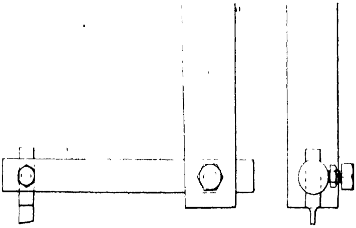

FIG. 12.—Tool-holder for keyway cutting.

cutting keyways. The nose of the tool in this case must be longer than the bore to be keywayed. In

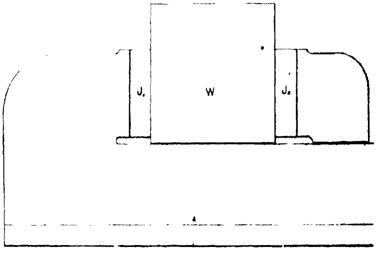

FIG. 13.—Use of machine vice.

Fig. 12 is shown a tool holder which carries an inserted tool of high-speed steel for the same purpose.

Methods of Holding Work-pieces.—The form and dimensions of a work-piece and the work which has to be done on it determine the most suitable

method of holding it in position on the table of a planer, shaper or slotter.

When the work-piece is of small dimensions the

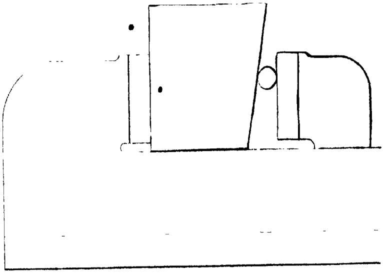

FIG. 14. Method of holding work piece in vice.

machine vice is frequently employed, as shown in Fig. 13, in which W represents the work-piece, J_1

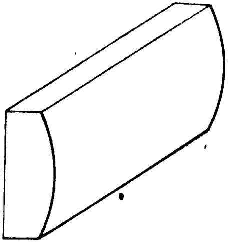

FIG. 15.—Packing-piece with curved face.

the fixed jaw of the vice, and J_2 the movable jaw. Unless the two opposite faces of W are parallel to each other, there is a tendency to cause the work-piece to heel-over slightly when the movable jaw is

being screwed up. There are several ways of counteracting this tendency: one of these is to use a cylindrical wire or rod between the movable jaw

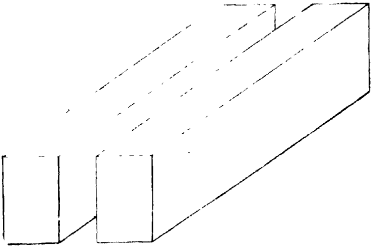

FIG. 16. Packing blocks or parallels.

and the work-piece, as shown in Fig. 14; another is to use a special packing strip with a curved face (Fig. 15) between this jaw and the work-piece.

If the depth of the work-piece is less than that of

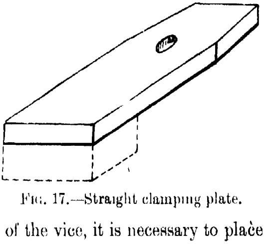

FIG. 17.—Straight clamping plate.

the jaws of the vice, it is necessary to place packing strips or blocks under the work-piece. These strips or blocks are usually rectangular prisms, as shown in Fig. 16.

The work-piece in every case is *bedded down* by

means of hammering, the sound produced indicating when the work-piece rests solidly on the bottom of the vice or on the packing block. If the work-piece is delicate, or its upper surface must not be

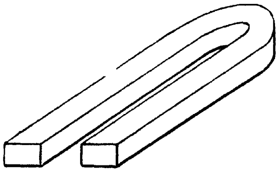

FIG. 18.—Clamping strap.

bruised, a copper or other safety hammer should be employed in the bedding-down operation.

Many work-pieces are clamped down directly on the table of the planing machine. In Fig. 17 is represented a simple form of clamping plate in

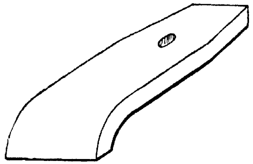

FIG. 19.—Bent clamping plate.

which there is a single hole or slot for the holding-down bolt. In Fig. 18 an open clamping strap is indicated. In each case a packing strip or block has to be used to support the plate or strap at one end, the height of this being, preferably, equal to that of the part of the work-piece on which it has to

rest. The use of such a strip or block is dispensed with when a clamping plate of the form shown in Fig. 19 is employed.

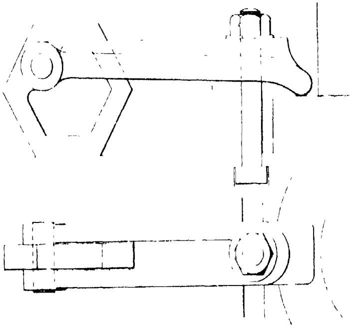

FIG. 20.—Clamping plate and adjustable packing.

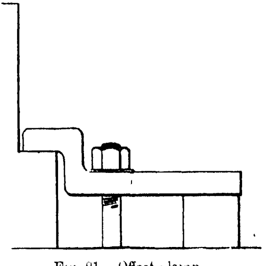

FIG. 21.—Offset clamp

An improved form of combined clamping plate and adjustable packing is illustrated in Fig. 20. In this form the packing is hexagonal in shape and

the clamping plate or finger is hinged to the block of a point other than the centre of the hexagon, so that either four or six heights of the packing are available

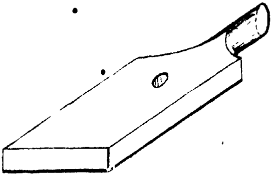

FIG. 22.—Finger clamping plate.

The use of an "offset" or "goose-neck" form of clamping plate is indicated in Fig. 21. In this case, of course, the height of the packing strip required is less than the height of the work-piece by an amount equal to the offset or length of the neck of the plate.

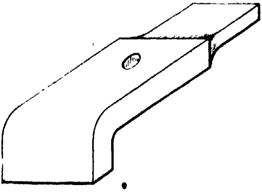

FIG. 23.—Tongue clamping plate.

All these forms of clamping plate are arranged to press directly on the outside of the work-piece. There are cases, however, in which it is not permissible to have a plate resting on the top of the work-piece, as, for example, when the work-piece

is a bar of square section which has to be planed over its four sides. In these cases, *finger clamps* (Fig. 22) may be used in conjunction with holes formed in the ends of the work-piece. A variation of the finger clamp is shown in Fig. 23, this form of clamp being known as the *tongue clamp*.

The use of finger clamping plates in conjunction with plain clamping plates for the purpose of holding down a long square bar, which has to be

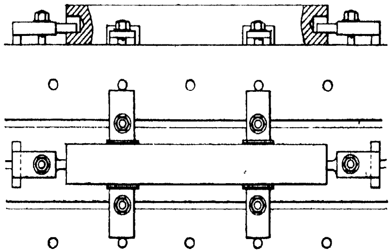

FIG. 24.—Method of holding bar of square section in planing machine.

machined completely over its four faces, is indicated in Fig. 24. It will be seen that no part of the holding-down apparatus projects above the upper face of the work-piece so as to foul the tool during either stroke of the table of the machine.

In Fig. 25 is shown a method of holding a work-piece of circular section for the purpose of machining a spline or keyway in it in the planing or shaping machine.

Position of Holding-down Bolt.—In connection with the use of clamping plates, as above, there is

one point that needs consideration probably more than any other. It has reference to the position of the holding-down bolt with respect to both the work-piece and the packing strip or block, and the influence of this upon the pressure which can be exerted by the plate on the surface of the work-piece for any given amount of axial stress in the shank of the holding-down bolt.

The conditions which obtain generally are in-

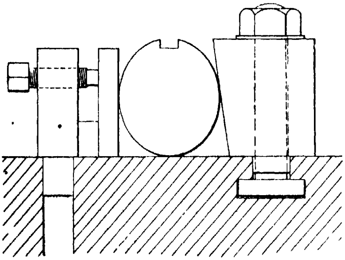

FIG. 25.—Method of holding work-piece of circular section.

dicated in Fig. 26. W represents the work-piece, and P the packing block. Assuming that the plate rests quite flat on each, and that it is not bent under the influence of the screwing-down force, F, we have the centre of pressure on the work-piece at the distance L from the centre of pressure on the packing block, and the latter at the distance l from the axis of the holding-down bolt. Then, if R represents the reaction from the surface of the work-piece, we have, by taking moments about the point A, the following relationship:—

$$R \times L = F \times l \quad . \quad . \quad . \quad (1)$$

where F = the axial force or stress in the bolt. By transposition we obtain

$$R = \frac{F \times l}{L} \quad . \quad . \quad . \quad . \quad (2)$$

Now, if we assume that F is constant, as we may, we see that the reaction from the work-piece surface which is equal to the pressure on the work-piece surface, depends entirely on the ratio, $\frac{l}{L}$, and the more nearly this approaches unity, the greater

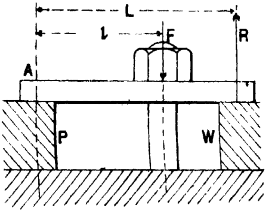

FIG. 26.—Position of holding-down bolt.

the value of R becomes. The practical deduction from this is that the holding-down bolt should be placed as near as possible to the work-piece.

Distortion of Work-pieces.—The work-pieces on planers and shapers are usually castings or forgings with comparatively rough and irregular surfaces. Care should therefore be taken in setting these up and fastening them down on the machine tables so that they are held securely. If there are any hollows under them, these should be filled with thin packing strips. Frequently strips of paper are

placed under castings to make allowance for the unevenness of the surfaces. If these precautions are not attended to, distortion of the work-piece will occur, and thus militate against the doing of satisfactory work.

Distortion may also occur—especially in castings—as the result of the removal of the skin, which, generally is harder than the interior or core, and holds the latter, more or less, in a state of stress. With the removal of this skin, the core tends naturally to assume an unstressed condition, this tendency always being attended by a change of shape. To obviate the effect of this somewhat, it is the usual practice wherever possible, which is not always, to rough-machine a casting all over before any one surface is finish-machined.

Setting-up Work-pieces on Planer and Shaper Tables.—If the table is known to be quite horizontal, the spirit level may be employed in the setting-up of a work-piece; otherwise the use of this instrument does not yield satisfactory results. The scribing block or surface gauge may, however, be employed in nearly every case of setting-up on the tables of these machines, whether the work-piece is supported directly on the table, mounted in or on a fixture or angle plate carried on the table, or held in a vice.

Setting the Tool in Position.—During the forward or cutting stroke of a planer or shaper, a certain amount of spring or deflection of the work-piece and of the tool occurs, with the result that on the backward or return stroke the tool is raised slightly as it is dragged over the surface of the work-piece.

This raising of the tool occurs whatever happens to be the disposition of the surface being tooled. In the case of vertical surfaces, it is desirable to swing the head through a small angle with respect to the

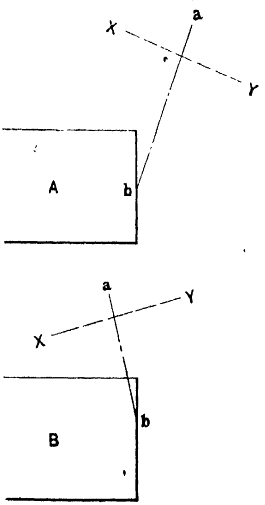

FIG. 27.—Diagram showing disposition of tool with respect to work-piece.

vertical, so that the axis of swing of the tool-box is not quite at right angles to the surface being tooled. Now, there are two directions in which the head can be swivelled: to the right and to the left. One of these is correct; the other incorrect. Which of the two is the correct one will depend upon the general

conditions obtaining in any given case. In Fig. 27, for one case, the correct direction is shown at A; the incorrect one at B. The two diagrams in this figure will explain why A is correct, and B incorrect. The line *ab* in each diagram represents the centre line of the tool. On the return stroke of the machine, this line swings about the axis of the tool-box, that is, the line XY. Obviously, in the case of A the point *b* will move away from the surface of the work-piece, whilst in the case of B it will move into it and so foul it.

In regard to the position of the cutting edge of the tool, this may be either immediately underneath the axis of swing of the tool-box or in front of it. To realise the former condition it is usually necessary to have recourse to the use of cranked tools; where these are not used, it is generally the latter condition which obtains. The difference beween the two conditions is indicated in Fig. 28. In this figure the former condition is represented by the tool in full outline, from which it will be seen that, under the influence of the cutting forces, the cutting point of the tool tends to dig further into the work-piece and so increase the depth of cut. The latter condition is represented by the tool in dotted outline, this showing that if deflection of the tool occurs, the result is a reduction in the depth of cut.

Cutting Speeds and Feeds.—The cutting speed in the case of a planing machine is the maximum linear speed at which the table or platen of the machine, and, therefore, the work-piece, moves during the active or cutting stroke, and is measured

either in feet per minute or metres per minute. The speed of the table during the return stroke does not affect the actual cutting, though it has a distinct influence upon the total time occupied to do a given amount of work in the machine.

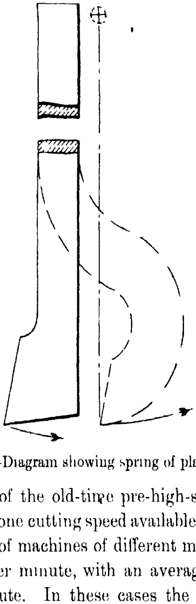

FIG. 28.—Diagram showing spring of planer tools.

On many of the old-time pre-high-speed planers there is only one cutting speed available, this ranging in the cases of machines of different makes from 20 to 26 feet per minute, with an average of, say, 23 feet per minute. In these cases the return speed varies from 50 to 80 feet per minute, with a bias towards the lower end of this range. These cutting speeds are quite suitable for the planing of such

materials as mild steel and cast iron with plain carbon steel tools, but they are rather low for the machining of aluminium, brass, gun-metal, and the softer metals generally This, however, never was a very serious defect, since the two former metals constitute the great majority of metals to be planed.

On modern high-speed planers the cutting speeds which are provided for are generally higher than the above, though where there are several speeds available the lowest is usually in the neighbourhood of 25 feet per minute. The highest cutting speeds in such cases range from 55 to 80 feet per minute, the return speeds ranging from 110 to 225 feet per minute. The ratio of the return speed and cutting speed is of some moment in connection with the question of the economy of working, and it is found that a ratio of from 3 to 4 to 1 gives acceptable results, though in one or two exceptional cases ratios as high as 9 or 10 to 1 have been adopted.

The number of cutting speeds on high-speed planers is very rarely greater than four, these being obtained by means of either (1) stepped-cone pulleys in the counter shaft, (2) a variable-speed cutting-stroke motor, or (3) a change-speed gear-box.

The cutting speed in the case of a shaping or slotting machine is the maximum linear speed at which the tool travels over the work-piece during the cutting stroke. With these machines the ratio of the return speed to the cutting speed is not so high as it is in the case of the planing machines; consequently, the economy of working may be a little greater in the latter case than in the former, though it must be noted that, pro rata, in the

planing machine the moving mass is greater than in the shaping or slotting machine.

The rack or gear-driven shaper has usually only one cutting speed, and this quite irrespective of the length of the stroke, that is, whether it is long or short. This is, of course, identical with the case of the ordinary planing machine. The shaper, however, whose ram is actuated by a crank, on the principle of the Whitworth quick-return mechanism, or a slotted or vibrating lever, is almost invariably equipped with a stepped-cone pulley or a change-speed gear-box, since the maximum cutting speed, as well as the maximum return speed, depends upon the length of the stroke, an increase in the latter always producing an increase in the former. In some extreme cas s, as many as 16 ram speeds (double strokes per minute, and not linear speeds) are provided for, though four is the usual number.

The average cutting speeds when plain carbon-steel tools are employed on different materials in the shaping and slotting machines are as follows :—

On cast steel	16 feet per minute.
„ „ iron	20 „ „ „
„ mild steel and wrought iron	24 „ „ „
„ brass	35 „ „ „
„ gun-metal	30 „ „ „

When high-speed tools or even ordinary self-hardening tools are employed, the above speeds may quite safely be multiplied by 2 and in some cases by 3.

If a tool cannot cut under the scale or skin of the casting or forging during the whole length of

the cut, it may be found necessary to reduce the speed slightly, where such a course is possible.

The manner in which the linear speed of the moving element of either a rack or screw-driven planer or shaper changes is indicated graphically in Fig. 29. In this figure, A represents the starting-point of the cutting stroke and the finishing-point

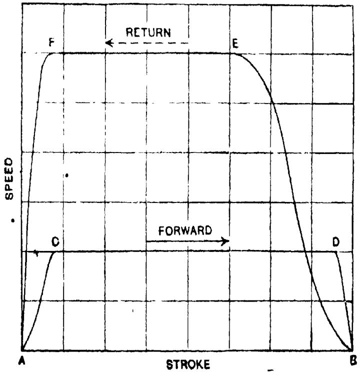

FIG. 29. - Speed diagram of planer or shaper.

of the return stroke, whilst B represents the finishing-point of the cutting stroke and the starting-point of the return stroke. The curve AC represents the period of increase of the cutting speed, the straight line CD the period of constant cutting speed, and the curve DB the period of decrease of the cutting speed. The three corresponding periods for the return stroke are represented by the curves BE, EF, and FA respectively. It will

be noticed that the period of increase of the return speed is much longer than the corresponding period for the cutting speed. This is, of course, a result that would naturally be expected on account of the considerable difference between the two speeds.

In all cases of machines of these three general forms, by "feed" is meant the movement of the cutting tool, relatively to the work-piece, in a direction normal to the direction of the main movement per cutting stroke. This can be varied considerably, so that in every case the feed most suitable for the material under operation and the kind of cut which is being taken can be selected. Only general rules can here be indicated. For roughing work, where much metal has to be removed, the usual and, undoubtedly, the best practice is to take as deep a cut as possible with a correspondingly fine feed; whilst for finishing, a very shallow cut (sometimes a mere scrape) with a coarse feed is usually taken, since in this case it is surface that has to be covered and not volume of metal that has to be removed.

CHAPTER II.

DRILLING, BORING, AND REAMING.

THESE are all internal cutting operations, and have as their common object the formation of round holes and bores. The operations are, however, readily distinguishable from one another, chiefly in regard to the machines and tools by means of which they are performed, and to the actual results which are attained by them.

Drilling.—This is essentially a hole-originating operation, and as such is differentiated from the other two, though, according to the modern dictionary, drilling and boring are synonyms, their common meaning in this connection being *piercing*. In drilling, holes are cut in solid work-pieces, the tools employed being of a number of varieties, but each variety generally has two cutting edges. Of all machine-tool operations, drilling is probably the most easily performed, especially in modern manufacturing works in which the repetitive principle of manufacture, involving the employment of jigs, is applied.

Drilling can be performed on the drilling machine, of which there are several varieties, the lathe, and the milling machine, and also by hand.

Boring.— This is a hole-enlarging operation, and

should be regarded only as such. The original hole may have been drilled, cored in the casting, or pierced in a press. It is reserved, generally, for the finishing of long holes of small diameter, such as gun and projectile bores, and shorter holes of large diameter, such as the bores of cylinders of reciprocating engines and the drums of turbine engines. The tools employed may have single cutting edges, two cutting edges, or a number of cutting edges, the number of cutting edges differentiating the tools from one another quite as much as the shapes of the cutting edges of the tools.

Boring can be performed on the drilling machine, the lathe, the vertical turning and boring mill, the horizontal boring machine, and the milling machine. It is very rarely performed by hand.

Reaming.—This is an operation which is, in principle, similar to boring. It differs from it, however, in regard to the lengths and diameters of the holes finished by this means. In this case only holes comparatively short, and of comparatively small diameters, are dealt with, whilst a further difference exists in the fact that a reamer is generally longer than the hole to be reamed, whereas the active part of a boring tool or cutter is not. Countersinking tools may be classed with reamers or boring tools according to the form of the hole produced, though in many cases the forms of the tools are not very different from those of drills, and, indeed, in some instances drills are actually employed in countersinking, which may be regarded as an operation whereby the end or mouth of an existing hole is enlarged and shaped.

The formation of tapered bores and holes is the work of boring tools and reamers, and cannot be accomplished by means of drills. Boring and reaming are finishing operations, drilling is very frequently a preliminary or roughing operation, and is only a finishing operation when no fine degree of accuracy or finish is required.

Drills.—Like other cutting tools, these are made of hardened tool-steel. Their shapes vary somewhat,

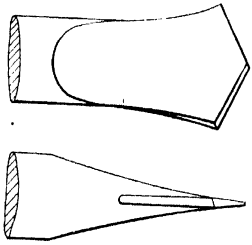

FIG. 30.—Point of flat drill.

though for manufacturing purposes the so called twist and twisted drills are chiefly employed.

The Flat Drill.—This is made in a variety of forms, the common feature of which is the point or cutting end, this being as indicated in Fig. 30. It has two cutting edges, and the drill point should be ground so that these are disposed at equal angles with respect to the axis of the drill; otherwise, unbalanced cutting will occur, and the service of the drill will be unsatisfactory. For special work on fairly hard material, a flat drill may be made out of an old file and used with fairly good results.

Accurate results cannot be secured continuously by means of the flat drill, and even when it is in its best condition it does not compare favourably

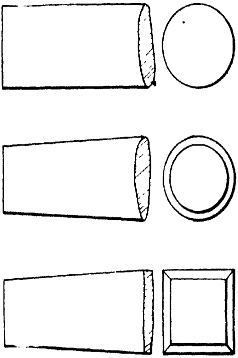

FIG. 31.—Flat-drill shanks.

with the twist drill. It is, however, useful in those cases wherein odd-sized holes have to be drilled.

The body of the flat drill is usually of circular

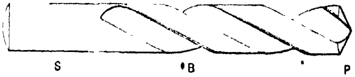

FIG. 32.—Twist drill.

section, and its shank (that is, its driving end) may be cylindrical, conical, or pyramidal, as shown in Fig. 31. The third form is suitable when the drill has to be used in a ratchet or hand brace.

A flat drill readily loses its size, owing to wear,

which occurs rather rapidly at the outer ends of the cutting edges.

The Twist Drill.—The cutting edges of a twist drill are two in number, these being formed at the ends of two spiral or helical grooves or flutes which are milled in the body of the drill opposite each other. A typical form of twist drill is shown in Fig. 32, the part lettered P being known as the *point*, that lettered B as the *body*, and that lettered S as the *shank*. The point is generally ground at an inclusive angle of 118° (that is, 59° on each side of the

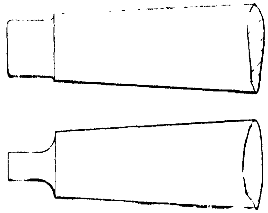

FIG. 33. Tapered twist-drill shank.

axis of the drill body), whilst the shank may be quite plain or cylindrical, as shown in this figure, or tapered, as shown in Fig. 33, with a tang at the end for driving purposes. The latter form admits of the use of the drill in a tapered socket, either in the end of the driving spindle or in a special fitting inserted therein. These fittings are of two kinds, as indicated in Fig. 34, the form A being known as a sleeve, and the form B as a socket. Each of these can be inserted in the socket of the driving spindle of the drilling machine or lathe, or the loose headstock mandrel of the lathe.

Care must be taken, however, to see that both flutes are treated exactly alike, so that the cutting action of the drill is a balanced one, a condition

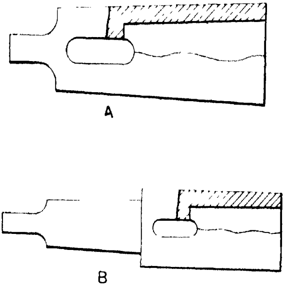

FIG. 34.—Twist-drill sleeve and socket.

which should always be satisfied for a number of reasons.

Twist-drill Rake.—The flutes of the ordinary

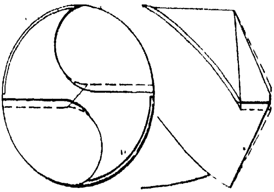

FIG. 35.—Point of twist-drill.

twist-drill are right-handed, and in virtue of this fact the lips of a twist-drill are automatically provided with cutting rake, the magnitude of which is equal to the angle of the flute spiral or helix. If it

is found that, for certain work, this angle is too great, it can be reduced by grinding on the flute in the manner indicated in Fig. 35.

Twist-drill Clearance. There are three kinds of clearance on a correctly made twist-drill. These are known as (1) longitudinal or body clearance; (2) circumferential or land clearance, and (3) lip or point clearance. The first is formed by grinding the body of the drill slightly smaller in diameter at the shank end than at the point, the difference in diameter varying from 0.0001" to 0.0003" per inch

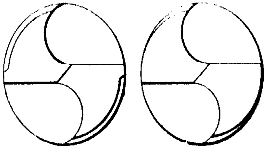

FIG. 36.—Forms of twist-drill land clearance.

of length of the body. The second is obtained by milling or grinding the body so as to form a narrow strip along the edge of each flute. These strips are known as "lands," and may be formed concentrically (A, Fig. 36) or eccentrically (B, Fig. 36). The third clearance is probably more important than either of the other two, since a drill may cut when these are absent, but it will not cut when there is no lip clearance. This clearance is obtained by grinding the point of the drill so as to form two lips, one behind each groove or flute, the grinding in each case being eccentric with the body of the drill, and of such an amount that the clearance

angle at the circumference on the cutting edge is approximately 15°, as shown in Fig. 37.

A rather curious point in connection with lip

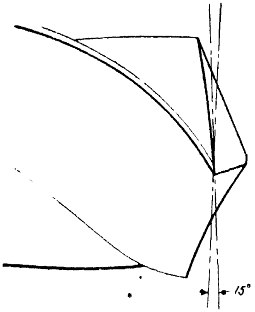

FIG. 37.—Twist-drill point clearance

clearance is to be found in the fact that the clearance angle should be greater near the middle of the point than towards the circumference. The explanation

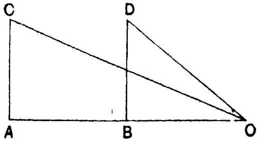

FIG. 38.—Diagram showing twist-drill point clearance.

of this is indicated diagrammatically in Fig. 38, in which AC and BD each represent the feed of a twist-drill per revolution of the drill, OA the circumference of the point near the outer end of the cutt-

ing edge, and OB the circumference near the middle of the point. The angles AOC and BOD represent the minimum or theoretical values of the lip clearances at the two places considered, and it will be seen that the angle associated with the smaller

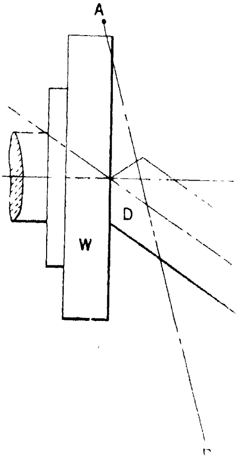

FIG. 39.—Principle of twist-drill grinding.

diameter or circumference is greater than the other. To obtain this condition it is necessary to grind twist-drills on a machine in a special attachment, the principle of action of which should be as shown in Fig. 39. In this figure, W represents the grinding wheel and D the drill. The front face of the wheel is generally used, and the twist-drill holder

should be capable of being swivelled about at axis AB, this being set approximately at 20° to the vertical face of the wheel.

The correctness of the grinding of a twist-drill can generally be determined by examination of the point of the drill. In Fig 40 are indicated the appearances of a twist-drill with insufficient clearance (A), one with the correct amount of clearance (B), and one without clearance (C)

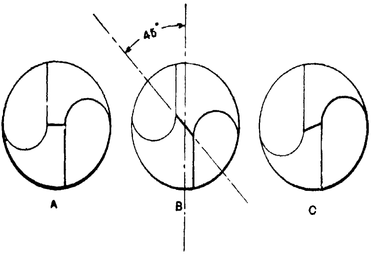

FIG. 40.—Effects of correct and incorrect grinding of a twist drill

The so-called chucking drill (Fig. 41) is, according to our original definition, not a drill at all, but a boring tool, since it can only enlarge existing holes—it cannot originate holes. It owes its name to the fact that it has three or four spiral flutes like those of a twist drill, but it has no sharp point.

The Twisted Drill.—This, in its modern form, is made only of high-speed and super-high-speed steel. It is made of either flat, rectangular stock, or grooved profile stock. In each case the drill blank is actually twisted, and not fluted. It is claimed for this form

of drill that it is, weight for weight, much stronger than the milled drill, since the natural fibres of the steel are not cut into, but only twisted.

The twisted drill is sometimes provided with a

FIG. 41.—Three-grooved chucking drill.

twist in its shank (which is invariably tapered), as shown in Fig. 42. By this means the grip of the shank of the drill in its socket is actually increased during cutting under the influence of the cutting

FIG. 42.—Twisted drill.

forces exerted, since these forces tend to untwist the stock of the drill.

The Straight-grooved Drill.—This is a drill with a straight groove, and as such it has no cutting

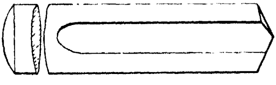

FIG. 43.—Straight-grooved drill.

rake. For this reason, it is extremely suitable for the drilling of brass work-pieces One form of it is illustrated in Fig. 43. Lip clearance and body clearance are ground on it in the same manner as in the case of the ordinary twist drill.

Boring Tools and Cutters.—A boring tool is usually employed in the lathe or the vertical boring

should be capable of being swivelled about at axis AB, this being set approximately at 20° to the vertical face of the wheel.

The correctness of the grinding of a twist-drill can generally be determined by examination of the point of the drill. In Fig 40 are indicated the appearances of a twist-drill with insufficient clearance (A), one with the correct amount of clearance (B), and one without clearance (C)

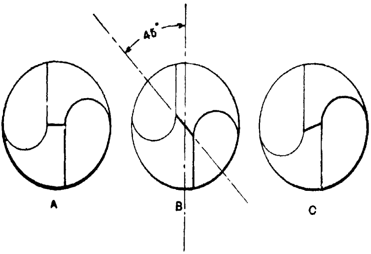

FIG. 40.—Effects of correct and incorrect grinding of a twist drill

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The Twisted Drill.—This, in its modern form, is made only of high-speed and super-high-speed steel. It is made of either flat, rectangular stock, or grooved profile stock. In each case the drill blank is actually twisted, and not fluted. It is claimed for this form

its end. In the latter case, the screw method, as illustrated in Fig. 48, is frequently resorted to.

A boring cutter-head must not be confounded with a boring bar cutter or a boring tool. It consists, generally, of a cylindrical body of cast iron or

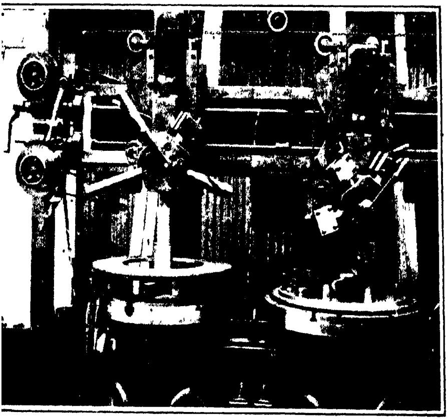


Fig. 46.—Boring operations.

mild steel (preferably the latter), in the periphery or side of which several cutters or blades are inserted One arrangement of cutters is indicated in Fig. 49. In this case six cutters are carried in the periphery of the head, and these are held in position in their respective slots or grooves by means of wedges or keys which are driven into circular holes in the

body. Another design of boring head is shown in Fig. 50. In this case, the cutters or blades are held in position by tapered wedges which are driven in the cutter slots immediately behind the cutters.

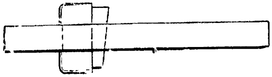


FIG. 47.—Boring bar.

A boring head may be fixed rigidly on its bar, or it may be mounted on it in such a way that, whilst it must rotate with the bar, it can be fed along it

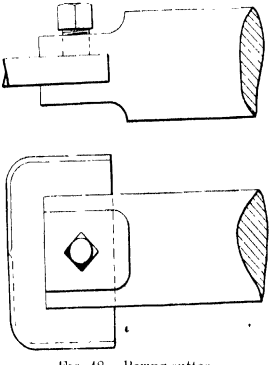


FIG. 48.—Boring cutter.

by means of a screw and nut under the control of wheel gearing driven by the bar itself or the driving spindle of the boring machine.

Reamers. These are essentially finishing tools, both in regard to condition of surface and dimen-

sions. They are themselves finished accurately to size on specially-designed grinding machines, and unless their cutting edges are maintained sharp, they do not yield satisfactory results.

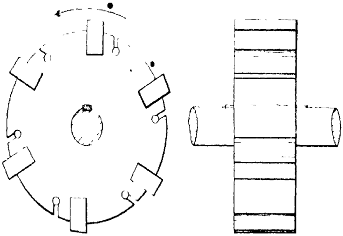


FIG. 49.—Boring cutter head.

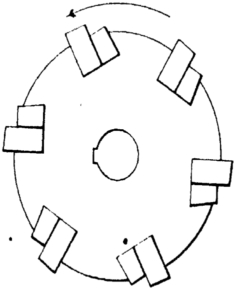


FIG. 50. Boring cutter head.

Reamers are of three general types: the solid reamer, the shell reamer, and the adjustable reamer. The last is specially useful where it is absolutely necessary to finish holes within certain fixed limits

of error. Reamers are further distinguished by the manner of their use, that is, whether they are used by hand or in a machine, such as a drilling machine or a lathe. Usually, only the first and third types are used in hand-reaming operations, whilst all three types are used in connection with machine-reaming operations.

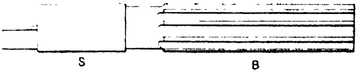


FIG. 51.—Hand reamer.

The Hand Reamer.—A solid form of hand reamer for finishing parallel holes is shown in Fig. 51. The main parts of this form of tool are a body B and a shank S, the latter having a square end on which a wrench of the form indicated in Fig. 52, or a similar form, is placed for the purpose of rotating the reamer about its own axis by hand.

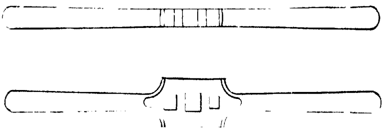


FIG. 52.—Wrench for reamers and taps.

The starting of a reamer in a hole is a matter involving both judgment and care, and even when these are exercised difficulty is sometimes experienced. To surmount this difficulty the self-feeding form of reamer is used. This is provided with a finely pitched screw thread on its teeth at the point, as represented in Fig. 53.

The sectional shape of a tooth of a hand reamer is indicated in Fig. 54, in which figure the angle θ is the relief or clearance angle and has, in practice, a value of from 3° to 5°. If the angle θ is greater

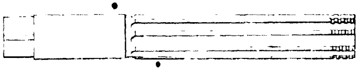


Fig. 53. Self feeding hand reamer

than 5° the teeth are generally too sharp or keen and tend to dig into the surface of the work-piece a tendency which militates strongly against the formation of a smooth surface. The teeth are formed

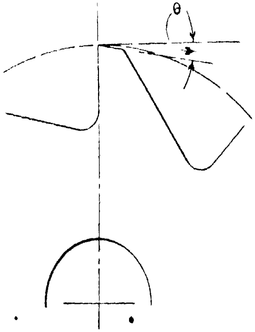


Fig. 54. Form of reamer tooth.

by flute-milling, the flutes in this case being straight and of the shape shown in the figure.

In the adjustable form of hand reamer, the cutting edges are formed on blades which are inserted in a mild-steel body, and held in such a manner that

they can be readily adjusted in position for the purpose of enlarging the reamer.

A simple form of adjustable reamer is indicated

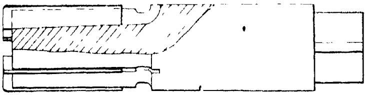


FIG. 55.—Adjustable hand reamer.

in Fig. 55. In this form the blades fit tightly in tapered grooves in the body, and when they are blunt they are driven up the grooves slightly and then ground again to the correct size. Such a form

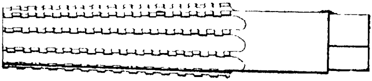


FIG. 56.—Roughing tapered reamer.

of adjustable reamer can be used in blind holes, a quality not possessed by all forms of adjustable reamers.

Tapered reamers are generally of two varieties:

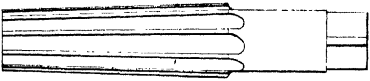


FIG. 57.—Finishing tapered reamer.

roughing and finishing reamers. The cutting edges of the former (Fig. 56) are preferably serrated or notched to break up the chips, whilst those of the latter (Fig. 57) must be continuous and unbroken to produce a smooth surface.

The sectional shape of a tooth of a hand reamer is indicated in Fig. 54, in which figure the angle θ is the relief or clearance angle and has, in practice, a value of from 3° to 5°. If the angle θ is greater

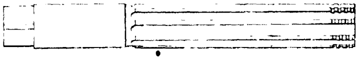


FIG. 53. Self feeding hand reamer.

than 5° the teeth are generally too sharp or keen and tend to dig into the surface of the work-piece a tendency which militates strongly against the formation of a smooth surface. The teeth are formed

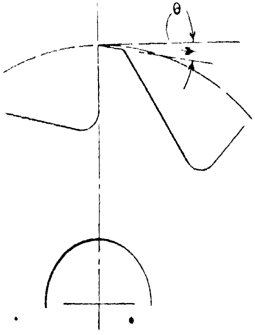


FIG. 54. Form of reamer tooth.

by flute-milling, the flutes in this case being straight and of the shape shown in the figure.

In the adjustable form of hand reamer, the cutting edges are formed on blades which are inserted in a mild-steel body, and held in such a manner that

and securing them rigidly thereto. The ordinary form of reamer shell is indicated in Fig. 59, from

FIG. 60. Combined centring drill and reamer.

which it will be seen that the shell is made of a single piece of steel, on which cutting edges are

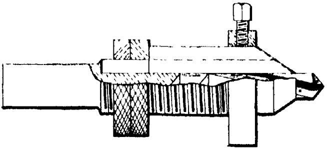


FIG. 61.—Combined centring drill and reamer.

formed, and in which there is a driving slot at the end.

The Combined Centring Drill and Reamer.—

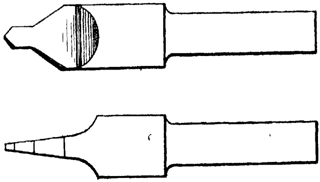


FIG 62.—Combined flat centring drill and reamer.

This is used in connection with the drilling and reaming (or countersinking) of the centre holes in the ends of work-pieces to be machined in the lathe or grinding machine. It exists in several forms,

four of which are represented in Figs. 60 to 63. The first and third of these, it will be observed, are solid, the first with a tapered and tanged shank and the other with a parallel shank, whilst the others are of the built-up type, the countersinking element of which in the one case is an inserted blade, and in the other teeth formed in the body of the reamer.

In Fig. 64 is shown the use of a double-ended combined centring drill and reamer in a bell-centring chuck, the employment of which avoids the necessity of marking-out and centre-punching for the centre hole in the end of the work-piece.

Reaming Allowance.—If too much metal is left

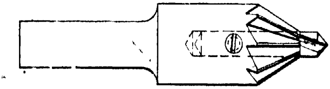


FIG. 63.—Combined centring drill and reamer.

in a hole to be reamed out, the cutting edges of the reamer are subjected to a very heavy duty, and they have a considerable tendency to blunt readily. At the same time, clogging in the flutes of the reamer is liable to occur, and this is very often accompanied by tearing of the metal, a condition which is always present when a rough surface is formed in a hole by a reamer. On the other hand, if too little metal is left in the hole, it may be found impossible to clean the hole up, that is, to remove in its entirety the surface formed in the hole in the previous machining operation. It, therefore, appears that the happy mean should be aimed at in every case. This mean depends upon the diameter and length of the hole

somewhat, but an average allowance may be taken at 0·005 inch per inch of diameter, with greater

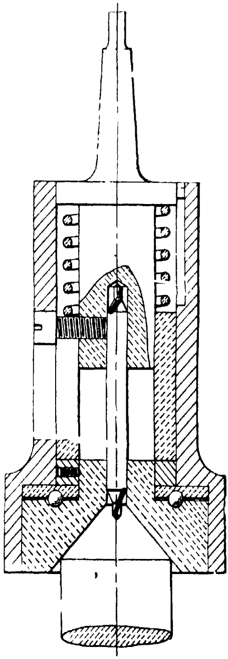


Fig. 64.—Bell centring chuck.

amounts in those cases where the length of the hole is greater than three diameters.

Trepanning or Coring.—This is essentially a hole-originating operation, though the diameter of the hole originated is generally much greater than could be obtained by means of drilling. A trepanning operation is illustrated in Fig. 65. A perusal of this figure will show that, unlike drilling,

FIG. 65.—Trepanning or coring operation.

this operation does not involve the breaking up of all the metal to be removed, but admits of a solid central part or core of metal being removed bodily. This, of course, results in a saving of material and, generally, of time. Some gun tubes and turbine drums are made from ingots or bars which have been trepanned so as to remove the interior of the

mass, which generally is the part which contains the greater number of flaws.

In Fig. 66 is illustrated one form of tool used for the formation of holes of comparatively large diameters in thin plates and sheets. It is a form of trepanning tool; though its use involves the drilling of an initial hole in which the pilot end or guide of the tool-bar revolves. It will be seen that the

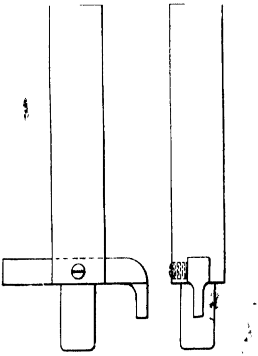


FIG. 66.—Cutter for large holes in thin material.

cutting element is secured in the bar by means of a small grub screw; an alternative arrangement embodies the use of a small cotter or wedge about the cutter. This form of tool is extremely useful in connection with the making of washers (when no better method is available), though in this case the pilot end of the bar is replaced by a flat-drill end.

Arboring.—This, strictly, is not an operation on a hole at all, though it has, generally, some connec-

tion with a hole. It is included amongst these operations, however, because, in some forms of arboring tools, cutters of the boring-cutter variety are used. Arboring is a form of the operation known as spot-facing, and is essentially a flat surface operation, and includes the facing of the undersides of flanges for bolt-head and nut seatings. In Fig 67 is represented one form of arboring tool, the cutter

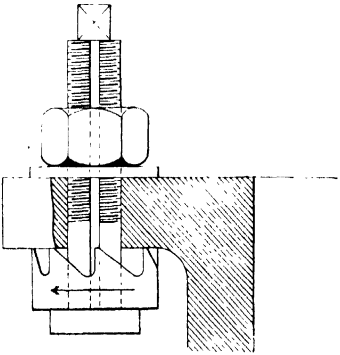


FIG. 67.—Facing tool.

in this case being provided with six or eight teeth and mounted on a splined rod The nut is used to put the feed on, so to speak. The tool, as a whole, is rotated by hand through the medium of the square end at the top. In place of the cutter with more than two teeth, frequently a flat facing cutter with two straight cutting edges is employed, this being inserted in a cross slot in the bar and held there by means of a small wedge or cotter. The

arrow on the diagram indicates the direction of motion of the tool when in actual use.

This operation is also performed on machines, drilling machines being those which are chiefly employed in this connection

Grinding Twist Drills. A twist drill, to be correctly ground at the point, must have its two cutting edges of equal lengths and inclined to the

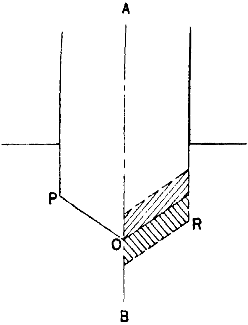


FIG. 68.—Diagram illustrating balanced drill action.

axis of the body of the drill at equal angles, and, unless these two conditions are satisfied, the drill will form a hole of a diameter greater than its own. The various possibilities in respect of this matter are indicated graphically in Figs. 68 to 72.

In Fig. 68 the correct conditions are represented. In this case each cutting edge (OP and OR) is of the same length and inclined at the same angle to the axis of the body of the drill, that is, the line AB in the figure. Consequently, the diameter of the

hole is the same as that of the drill, and each cutting edge takes one-half of the feed and does one-half of the work.

The case wherein the two cutting edges are of equal lengths, but inclined at different angles to the axis of the body of the drill is represented in Fig 69 In this figure O is the point of the drill and AB is the axis of the body of the drill It will be

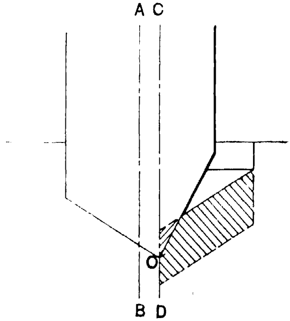


FIG. 69.—Diagram illustrating unbalanced drill action.

noticed that the point O is not contained in the line AB, but in the line CD, which is parallel to AB. Hence, the axis of revolution is CO and *not* AB, and the hole is made of a diameter larger than that of the drill, nearly all the work being done by one cutting edge, namely, the one which is inclined to the body axis at the greater angle. The relation between the amounts of work done by the two cutting edges is represented by the ratio between the two sectioned areas.

In Fig. 70 is illustrated the case wherein the two cutting edges are at equal inclinations to the body axis (AB), but are of unequal lengths. Here also the point O is not contained in the body axis AB, but in the line CD, which is the axis of revolution. Here, however, the disparity between the amounts of work done by the two cutting edges is not as great as in the above case, a result which is obvious

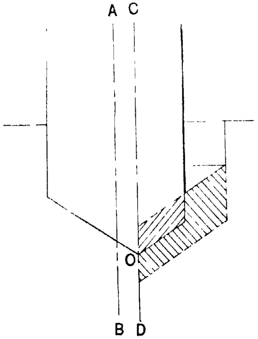


FIG. 70.—Diagram illustrating unbalanced drill action.

when the two sets of sectioned areas are compared with each other. As in the second case above, the diameter of the hole formed under these circumstances is larger than the diameter of the drill.

In Figs. 71 and 72 are indicated the two sets of conditions embracing inequality in length and inequality in inclination of the two cutting edges. In the case of Fig. 71, the longer cutting edge is inclined at the greater angle to the body axis, whilst

in the other case it is the shorter cutting edge which is so inclined. This difference between the two cases, it will be noticed, results in a difference in the relation between the amounts of work done by the two cutting edges, the ratio between the two amounts being less in the latter case than in the former. On the other hand, both drills produce holes of diameters greater than their own.

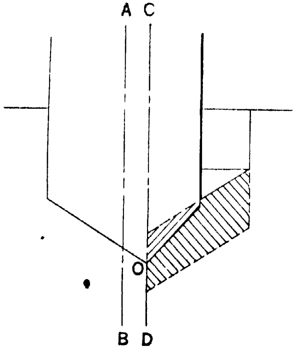


FIG. 71.—Diagram illustrating unbalanced drill action.

All the conditions represented in the last four figures are also unsatisfactory for the reason that the drill in each case has to revolve about one axis at its cutting end, and about another at its driving end. This induces unnecessary torsional and bending stresses in the drill, and is one of the most prolific causes of fracture in drills.

It is, therefore, necessary to see that both cutting edges are of equal lengths and inclined at equal

angles to the axis of the body of the drill. The inclination should be dealt with first, as it is much easier to alter the length of either cutting edge after the correct inclination has been secured than it is to alter the inclination after the correct length has been obtained in fact, the latter feat is almost an impossibility.

The inclination of the cutting edge of a twist

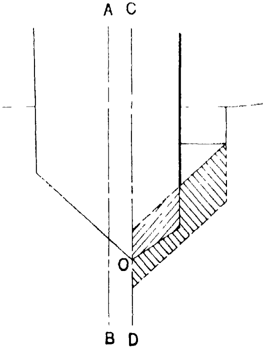


FIG. 72.—Diagram illustrating unbalanced drill action.

drill can be checked by means of a bevel protractor, a bevel gauge, or an angle template such as is shown in Fig. 73. The length of the cutting edge can be determined directly by means of a graduated rule or a scale marked on the angle template (Fig. 73). An indirect method, which is quite as suitable as either direct method, is indicated in Fig. 74. In this case, the axial distance of the outer end of the cutting edge from the inner end, or point of the

drill, is measured on the graduated blade ordinary square.

Grinding Reamers. Reamers can be satisfactorily ground only on special tool and cutter grinding machines, in which the reamers are held in special relation to the grinding wheels during

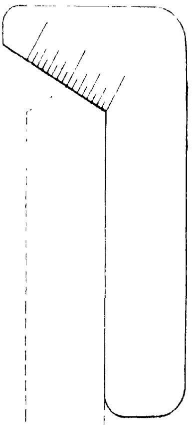


FIG. 73.—Drill-grinding template.

the operation of grinding. Each reamer is mounted between centres on the table of the machine, and the teeth are ground one at a time, the particular tooth under operation being preferably held against a tooth rest or guide finger. Generally, two forms of grinding wheel are available for this kind of work, the disc form and the cup form. The former

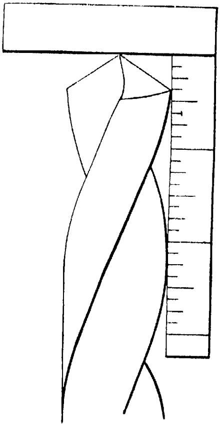


FIG. 74.—Use of graduated square in drill grinding.

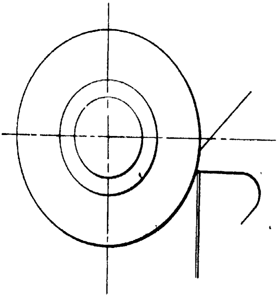


FIG. 75.—Grinding reamer teeth with disc wheel.

is shown in Fig. 75, and forms a hollow or concave tooth-land, whilst the latter, which is indicated in Fig. 76, forms a flat tooth-land. Of these two forms of land, the latter is preferable, since the cutting edge which accompanies it is slightly stronger than the cutting edge which belongs to the other form of land. There is another form of tooth-land which is in use, though to a very limited extent, chiefly on account of the special character of

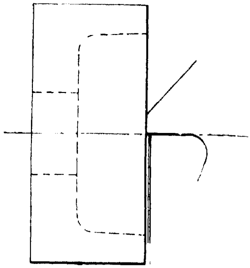


FIG. 76.—Grinding reamer teeth with cup wheel.

the equipment which is required for its production. It is a curved land like the concave land, but the curvature is outwards (Fig. 77) and not inwards, the curvature being that of a circular arc which is eccentric with the circle passing through the cutting points of the teeth of the reamer.

Drilling in the Lathe.—Work-pieces of simple shape—such as plain forged steel discs or iron castings—have frequently to be drilled and faced up in the lathe. In such cases it is customary to grip the work-piece (W, Fig. 78) in a four-jawed chuck

of the independent jaw type, and to force the drill through the work-piece through the medium of the loose-headstock mandrel. The drill D may be either

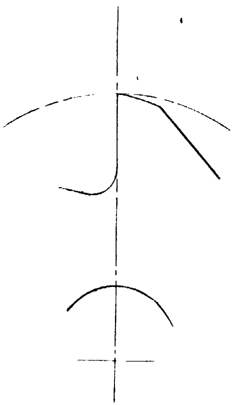


FIG 77 - Reamer tooth with convex land.

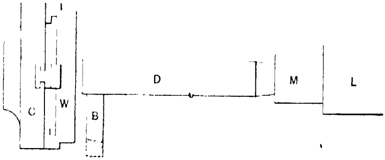


FIG. 78.—Drilling in the lathe.

socketed in the headstock mandrel M or mounted on the headstock centre. In the former case, the frictional grip between the mandrel socket and the

drill shank is usually sufficient to admit of the drill being forced through the work-piece without slipping. In the latter case, a lathe carrier is usually mounted on the shank of the drill, and this is held either in the hand or against the upper part of the slide rest.

To guide the drill at the start, it is generally found desirable to use a small bar B, such as the shank of a lathe tool, by securing it in the tool holder of the slide-rest and feeding up against the drill, as is indicated in the figure.

For the drilling of fairly hard steel forgings in the lathe it is sometimes found that a drill of the flat-drill type will yield better results than will a twist drill. This is probably partly due to the fact that with the former type of drill there is more chip room than with the latter, though it has no self-clearing properties.

Drilling by Means of Jigs.—When a large number of identical work-pieces have to be drilled in precisely the same manner, modern practice ordains the use of a jig or jigs. The object to be attained in the use of jigs is not merely the drilling of all the work-pieces alike, but also a considerable reduction in the time occupied upon the work. The gain resulting from this time-reduction is offset somewhat by the cost of making the jig or jigs, and also by the fact that the life of the jig or jigs is limited.

The essential features of a drilling jig are (1) accommodation for each work-piece in one position in the jig, and (2) elements for guiding the drill or drills at pre-determined points in relation to the

position of the work-piece in the jig. The guiding elements are usually hardened-steel bushes inserted in the frame or body of the jig. The general design of a drilling jig depends upon (1) the general dimensions of the work-piece, (2) the general shape of the

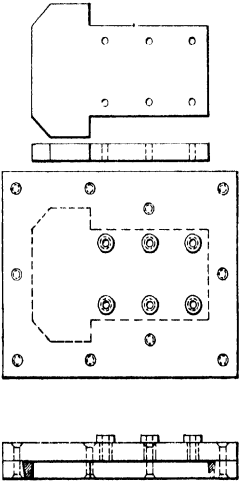


FIG. 79.—Drilling jig

work-piece, (3) the diameters of the holes to be drilled, and (4) the number of, and relation between, the holes to be drilled.

The two chief classes of jigs are (1) the plate jig and (2) the box jig. A simple example of the former class is indicated in Fig. 79. In this case, the work-pieces to be drilled are of the shape shown in

the upper part of the figure in plan and elevation, and has to have six holes drilled in it as shown. The jig is made of two pieces of sheet steel riveted together, the lower one being shaped internally to suit the work-pieces, whilst in the upper one the guide bushes for the drill are inserted. When in use this form of jig is simply held down over the work-piece on the table of the drilling machine by hand. Where the work-piece is not thin in any one direction, generally it has to be secured mechanically in the jig.

It should be observed that, in drilling by means of jigs, the process of marking-out is almost invariably entirely dispensed with, though it is occasionally necessary to precede the drilling operation by some other machining operation for the purpose of forming one or more definite locating surfaces on each work-piece.

Drill Sizes.—Many of the twist drills of the smaller sizes are made from drawn steel rod or wire, whose dimensions are based upon the Stubs' steel-wire gauge system. In this system, each diameter which is included is associated with a given number or letter, all the numbers from 1 to 80 and all the letters of the English alphabet being used. In Table 1 of the Appendix is given a list of the decimal equivalents in English measure of the 106 gauge numbers and letters of this system, which must not be confused with the Stubs' iron-wire gauge system.

Drills of the larger sizes, and some of the smaller sizes, are made in even fractions of an inch or multiples of a millimetre.

Drilling Speeds and Feeds.—The speed of a drill is usually given as an angular speed, that is, in revolutions per minute. It is, however, the surface or circumferential speed of the drill that determines the angular speed, since it is upon the former that the endurance of the cutting edges of the drill depends.

The ordinary linear feed of a drill is definable in two ways; in the first, it is defined as the longitudinal or axial movement of the drill per revolution of itself; in the second, it is defined as the number of revolutions made by the drill per inch of longitudinal movement of itself. It is obvious that these two quantities are reciprocals of one another, the first being a distance, and the second a number.

The most suitable combination of cutting speed and feed in any given case will depend very largely on conditions connected with the nature of the metal to be drilled, its physical condition, the form and rigidity of the drilling machine, and the condition of the drill. It is possible, however, to distinguish between plain carbon-steel drilling and high-speed drilling.

With carbon-steel drills, the surface cutting-speeds used when drilling iron and steel range from 12 to 28 feet per minute, whilst in connection with the drilling of brass and bronze the surface speeds vary from 20 to 40 feet per minute. An average drilling speed for iron and steel with carbon-steel drills may, therefore, be taken at 20 feet per minute, and that for brass and bronze under the same conditions at 30 feet per minute.

With high-speed drills, the above surface cutting speeds may be quite safely increased threefold.

With both plain carbon-steel and high-speed drills the feed (in inches per revolution of the drill) depends upon the diameter of the drill, any increase in the latter requiring an almost proportionate increase in the former Generally, the feeds of high-speed drills are greater than those of plain carbon-steel drills.

In Table II of the Appendix is given a list of average angular speeds and corresponding feeds for plain carbon-steel drills of different diameters when used on iron and steel and on brass and bronze. In Table III. of the Appendix is given a similar list for use in connection with the employment of high-speed drills.

General Observations on Drilling.—A drill to cut effectively must have its cutting edges maintained sharp and correctly formed, it being a sheer waste of time to attempt to force a blunt drill through a work-piece.

The employment of a copious flow of a good compound having cooling and lubricating properties when drilling undoubtedly extends the life of the cutting edges of a drill to a great extent, whilst it also slightly reduces the amount of power required in the drilling operation. To obtain the best results, however, the supply of compound to the drill must be a very copious one, preferably under a slight pressure. An old-time compound is one containing soft soap, soda, and water, but the more modern so-called soluble oils or cutting compounds have largely taken the place of this. These new compounds contain a pine oil and an animal oil as essential ingredients, and whilst some are miscible

with water and form comparatively clear solutions, others are not miscible and form emulsions or semi-emulsions.

Cast iron should be drilled without the use of a cutting compound.

Before a drill is inserted in a socket or sleeve, care should be taken to see that the shank of the drill is quite clean and that no small particles of dirt or metal are adhering to it Failure to attend to this matter is the most prolific cause of damage to sleeves and sockets and to the shanks of twist drills.

Generally, a truer hole can be obtained with a rotating work-piece and a stationary drill than with a rotating drill and a stationary work-piece. In fact, it is possible to drill a disc of the size of a sixpence across a diameter from circumference to circumference without breaking through in either direction, if the disc can be revolved and the drill simply fed into it.

CHAPTER III.

MILLING.

THE process of metal-milling, which is of such tremendous importance at the present time, is by no means of recent origin, but it was not a practical success until the development of the modern grinding process and the means whereby the teeth of milling cutters could be ground accurately and expeditiously. And even then the cost of the cutters required and their apparent fragility stood for a long time as a bar to the progress of the process. To-day the principles underlying milling are better understood, so that the process has been able to take its rightful place in the engineering workshop.

Milling may be regarded as a process of removing metal from stock by means of revolving cutters (which usually have a comparatively large number of teeth). It is, however, distinctively different from boring and reaming, inasmuch as it is mainly a process which is applied to the exteriors of work-pieces; and where it is applied to interiors, a difference between the two sets of processes exists in the fact that boring cutters and reamers fill the bores or holes that they work in, whereas the diameter of a milling cutter is generally much less

than the diameter of the hole in which it is working.

Milling Machines.—They may be classified as follows :—

1. Lincoln milling machines, with horizontal spindles.
2. Plain pillar-and-knee milling machines.
3. Universal horizontal milling machines.
4. Plano-millers, or slabbing machines.
5. Vertical-spindle milling-machines.
6. Gear-cutting machines.
7. Special milling machines, for such work as twist-drill fluting and thread-milling

The first, second, and fourth types are suitable only for the production of flat or plane surfaces on work-pieces. The plano-miller is much used in connection with the machining of petrol-engine crank-cases and automobile gear-boxes in large quantities, this being done with the aid of jigs and special fixtures.

The third type is of such a design that practically every known form of milling can be done on it, though not always in the most expeditious manner. Plane surfaces, horizontal, vertical, and oblique, can be milled ; all kinds of tools can be fluted, with either straight or curved flutes ; gear wheels of the spur, level, spiral, and worm varieties can be cut ; and the most complicated work involving spirals and angles and indexing can be done in it.

The fifth type comprises two sub-types, the plain machine and the profiling machine. On the former, generally, only comparatively plain work can be done. On the latter, in addition to plain work, the

special work of profile-formation can be done, with or without the aid of formers or copies.

The sixth type comprises machines known as gear-cutting or gear-milling machines and gear-hobbing machines. They are a development of the universal milling machine, but they have nothing universal in their character, though the principle of some of their movements is practically the same as that of the movements of the universal milling machine.

Twist-drill fluting machines are highly specialised machines. Generally, their design is such that the two flutes of a twist-drill are milled out at the same time, or that two drills have each a flute milled out simultaneously. There are several methods of attaining either of these objects.

Thread-milling is the latest of the milling processes. By means of it, screw threads are cut much more expeditiously than with single-pointed cutting tools or chasers, though, in connection with square-thread cutting, it does not yield accurate results.

Types of Milling Cutters.—Milling cutters may be classified in several ways. The first classification divides them into fluted cutters, formed cutters, and inserted-tooth cutters. Cutters of the first two classes are invariably solid cutters in themselves, or built up of solid-cutter elements. Cutters of the third class are always made up of mild-steel or cast-iron bodies, in which are inserted and rigidly secured the blades or cutting elements.

Fluted Milling Cutters.—The teeth of milling cutters of the fluted variety are of two principal types, namely, those with straight cutting edges and

those with curved cutting edges. Each principal type can be divided into three sub-types, according to the character of the surface in which the cutting edges of the teeth can be supposed to be situated.

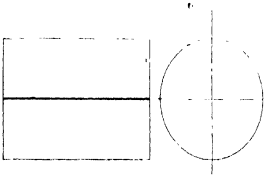


FIG. 80.—Direction and position of axial cutting edge.

The three sub-types of straight cutting edges are: (1) the axial cutting edge, that is the cutting edge which is parallel to the axis of the cutter, (2) the radial cutting edge, that is, the cutting edge which forms a radius to the cutter section normal to the

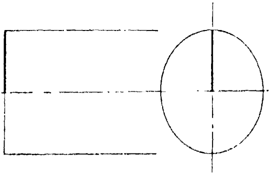


FIG. 81.—Direction and position of radial cutting edge.

cutter axis; and (3) the inclined or oblique cutting edge, that is, the cutting edge which is inclined to both the axis of the cutter and its normal sections. Cutting edges of the first sub-type are invariably situated in a cylindrical surface (Fig. 80); those of the second sub-type always in a flat or plane sur-

face (Fig. 81); whilst those of the third sub-type are always situated in a conical surface (Fig. 82).

Of the curved cutting edges, the three sub-types are: (1) the helical cutting edge (sometimes, though

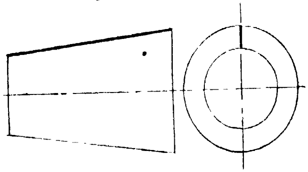


FIG. 82.—Direction and position of oblique cutting edge.

wrongly, described as the spiral cutting edge), that is, the cutting edge which is in the form of a helix; (2) the spiral cutting edge, that is, the cutting edge which is in the form of a true spiral; and (3) the volute cutting edge, that is, the cutting edge which

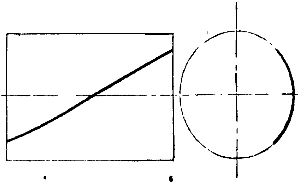


FIG. 83.—Direction and position of helical cutting edge.

is in the form of a volute. Cutting edges of the first of these three sub-types are always situated in a cylindrical surface (Fig. 83), those of the second sub-type invariably in a flat or plane surface (Fig. 84); and those of the third sub-type always in a conical surface (Fig. 85).

The cutting edges of a fluted milling cutter are obtained by forming teeth by the fluting process,

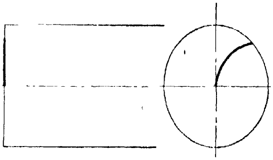


FIG. 84.—Direction and position of spiral cutting edge.

and the description of the cutting edge of a fluted milling-cutter tooth always defines the tooth. Thus,

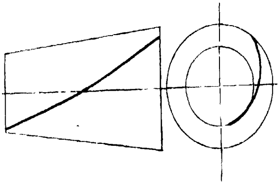


FIG. 85.—Direction and position of volute cutting edge.

a tooth which has a helical cutting edge is known as a helical tooth, and this description is sometimes

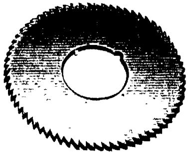


FIG. 86.—Slitting saw.

given to the cutter, the only excuse for which, however, is the brevity of the description.

Axial teeth are to be seen on the slitting cutter shown in Fig. 86, on the end mill shown in Fig. 87, and on the side-and-face or slotting cutter indicated in Fig. 88. Radial teeth are indicated on the end

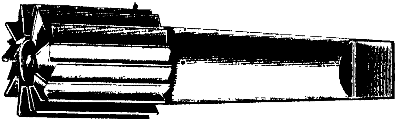


FIG. 87 End mill

mill in Fig. 87 and on the slotting cutter in Fig. 88, they are also to be found on cutters which are known as single-angle milling cutters, somewhat like the angular cutter indicated in Fig. 89, but with one face normal to the axis of the cutter. Inclined or

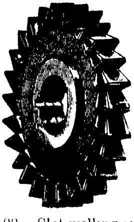


FIG. 88.—Slot milling cutter.

oblique teeth are to be found on angular and dovetail cutters, as in the case of the double-angle milling cutter represented in Fig. 89. Helical teeth are used chiefly on plain milling cutters, such as illustrated in Fig. 90, and end milling cutters. True spiral and volute teeth are not ordinarily used, but only in special cases.

Plain milling cutters have only either axial or helical teeth, that is, only one set of teeth and not several, as is the case with other forms of fluted milling cutters. Plain milling cutters are those which are ordinarily employed in the formation of flat or plane surfaces of work-pieces of a general character. The teeth, instead of being individually continuous from end to end, are sometimes nicked or notched to break up the chips which are formed in the cutting operation, and so prevent clogging

FIG. 89.—Angular milling cutter.

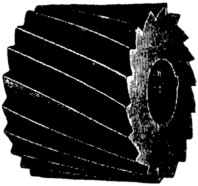


FIG. 90.—Plain milling cutter with helical teeth.

in the flutes of the cutter. A plain milling cutter with helical teeth is indicated in Fig. 90.

The usual shape of the teeth of a plain milling cutter taken in a plane at right angles to the axis of the cutter is shown in Fig. 91. On the outside the tooth is bounded by three surfaces which are indicated more distinctly in the enlarged diagram in Fig. 92. The point A in this figure represents the cutting edge of the tooth; the line AB represents the narrow surface on the tooth immediately behind the cutting edge which is known as the *land* of the

Axial teeth are to be seen on the slitting cutter shown in Fig. 86, on the end mill shown in Fig. 87, and on the side-and-face or slotting cutter indicated in Fig. 88. Radial teeth are indicated on the end

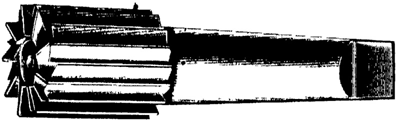


FIG. 87 End mill

mill in Fig. 87 and on the slotting cutter in Fig. 88, they are also to be found on cutters which are known as single-angle milling cutters, somewhat like the angular cutter indicated in Fig. 89, but with one face normal to the axis of the cutter. Inclined or

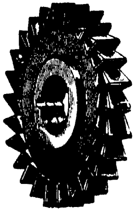


FIG. 88.—Slot milling cutter.

oblique teeth are to be found on angular and dovetail cutters, as in the case of the double-angle milling cutter represented in Fig. 89. Helical teeth are used chiefly on plain milling cutters, such as illustrated in Fig. 90, and end milling cutters. True spiral and volute teeth are not ordinarily used, but only in special cases.

crease in the efficiency of cutting action of a milling cutter on such materials as mild steel and cast iron is registered when the teeth are provided with an amount of *positive* front rake, as is indicated in the upper diagram in Fig. 93 by the angle ϕ. On the other hand, milling cutters for use on such materials as brass and bronze give much better results if their teeth are so formed that their front cutting faces slope outwards and not inwards, that is, if their teeth have an amount of *negative* front rake, as is in-

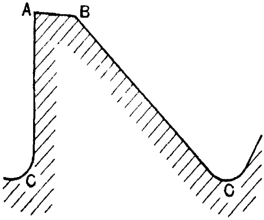
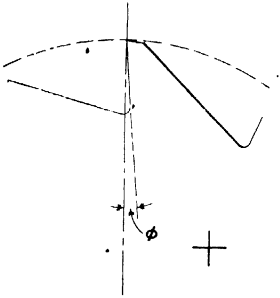


FIG. 92.—Section of milling-cutter tooth.

dicated by the angle ϕ in the lower diagram in Fig. 93.

The helical form of tooth for this type of milling cutter is preferable to the straight axial form. This is owing to the fact that, when the straight tooth is in action, the entire active length of the cutting edge of the tooth comes into action at one instant, as is shown in Fig. 94, in which the two arrows indicate the instantaneous directions of motion of the work-piece and the cutting edge; whilst, when the helical form of tooth is at work, the active part of its cutting edge moves into action gradually, starting at one end

and passing across the work-piece to the other end, as is indicated in Fig. 95. The result of this differ-



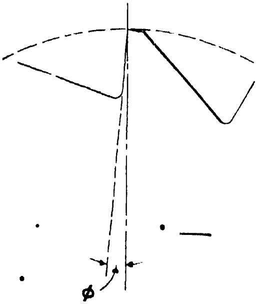


FIG. 93.—Milling-cutter rake.

ence is that the straight tooth moves into action with a shock, starting with a cut of full width, whereas

the helical tooth starts its cutting action without shock of any kind, and gradually increases the width of its cut.

A point which merits attention in connection with plain milling cutters and, in fact, nearly all milling cutters which are provided with central holes, is in regard to the form of the holes. If the hole is made quite plain and of one diameter, it is always found

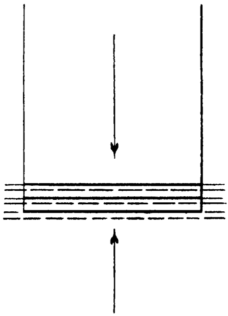


FIG. 94.—Cutting action of axial teeth.

that, after the cutter has been hardened and, where necessary, tempered, the hole is no longer cylindrical and of one diameter from end to end, but is bell-mouthed at each end, as is shown in Fig. 96, the diameter of the hole at either end being larger than any diameter near the middle section of the cutter. This is probably due to the fact that the two ends of the cutter cool much more rapidly than does the middle portion, so that the latter has more time in which to contract from its expanded dimensions due

to the heating of the cutter. With such a hole, it is necessary to grind or lap it out to a true cylindrical form of the correct diameter, the whole internal

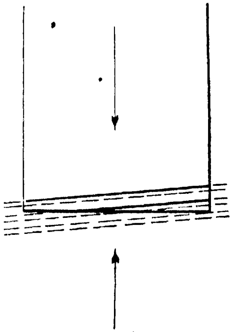


FIG. 95.—Cutting action of helical teeth.

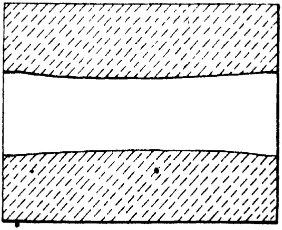


FIG. 96.—Distortion of milling cutter due to hardening.

surface of the hole having to be worked on. This is generally a troublesome and tedious operation, whether the work is done by grinding or by lapping,

so that it is customary to hollow or chamber out the hole, as is indicated in Fig 97 This hollowing or chambering out does not prevent the cutter from coming out of the hardening operation with a hole having bell-mouthed ends, but it causes the greater part of the curving that takes place to occur outside of the diameter of the finished hole, and so considerably reduces the amount of work which is involved in the grinding or lapping out of the hole

The diameter of the hole of a plain milling cutter

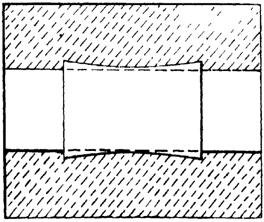


FIG. 97.—Chambering in hole of milling cutter.

should be made between the specified limits for a push or sliding fit, the arbor on which the cutter is to be mounted, and by which it is to be driven, being made of the nominal standard diameter.

The end milling cutter, or end mill as it is very often designated, is generally designed for use in a spindle socket: hence its tapered and tanged shank. The end or side teeth are nearly always radial; whilst the face or body teeth may be either straight or helical, the hand of the helix, in the latter case, being either right or left.

The question of the hand of the body-tooth helix

of an end milling cutter is a somewhat important one, since the combination of this and the hand of the cutter in each case determines the rake of the end or side teeth, and these teeth are quite as much used as are the body teeth, and they are real cutting elements in all end milling operations. If we designate the hand of the cutter according to the direction in which it revolves, when its free end is observed,

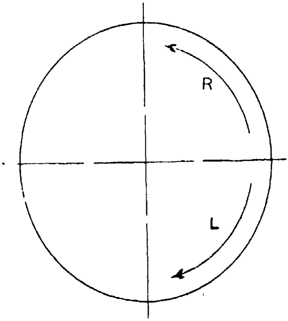


FIG. 98.—Right and left hand of milling cutters.

we shall say that a cutter is a right-hand cutter if it revolves in a counter-clockwise direction (as indicated by the arrow R in Fig. 98), and a left-hand cutter if it revolves in a clockwise direction (as represented by the arrow L in the same figure). Based upon this definition, we have that the combination of (*a*) a right-hand cutter and a right-hand body-tooth helix (A, Fig. 99) or (*b*) a left-hand cutter and a left-hand body-tooth helix (B, Fig. 99) forms end teeth with positive rake, whilst if the two hands are opposite

(C and D, Fig. 99) the rake formed on the end teeth is negative, and the cutting capabilities of the cutter are not as good as with teeth having positive rake. With a straight or axial tooth on the face, obviously, the radial tooth has an axial front cutting face and, therefore, no rake at all.

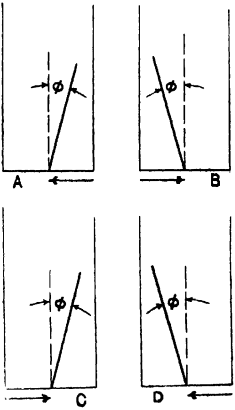


FIG. 99.—End milling-cutter rake.

In Fig. 100 is represented a simple form of end milling cutter which is exceedingly useful on such materials as brass and fibre. It is practically the only form of milling cutter with two cutting edges, and hence stands in a class by itself. It is neither a fluted nor a formed milling cutter, but is made in somewhat the same way as are certain types of boring and facing cutters.

Angular mills are of either the single-angle or double-angle variety. In the single-angle form there may be either one or two sets of teeth: if there are two sets, one is of radial teeth, and the other of inclined oblique teeth; if there is only one set, then this is of inclined or oblique teeth. The form having two sets of teeth has a slightly better cutting action than the other. The angle may be either right-hand

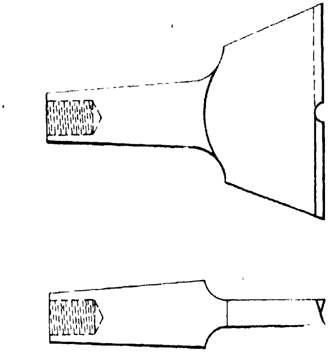


FIG. 100.—Simple form of end mill.

or left-hand, the hand of the angle being identical with the hand of the cutter, the latter being determined by the direction of rotation of the cutter when observation is made towards the flat end of the cutter, as represented by the arrow in Fig. 101. In this case, the rule which is represented graphically by Fig. 98 is applicable. The magnitude of the angle may be anything between 0° and 90°, though standard single-angle cutters are made of definite

angles, such as 60°, 75°, 80°, etc. Single-angle milling cutters are employed as fluting cutters for the formation of axial, radial, and inclined milling-cutter teeth. In the double-angle form of cutter, one of the angles is usually—though not quite always—much smaller than the other angle, and there are always two sets of inclined or oblique teeth, one set on each side of the cutter, the cutter really consisting of two

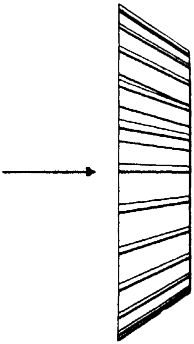


FIG. 101.—Single-angle milling cutter.

cones of teeth placed end to end. These cutters are employed for the formation of axial, helical, spiral, and volute teeth, and in such cases the small side angle is either 12° or 15°, whilst the large main angle is either 40°, 48°, 53°, or 60°. The hand of a double-angle milling cutter is determined by observing the direction in which the cutter would revolve when looking towards its small-angle face. Double-angle cutters which have both angles equal are chiefly used

for such operations as the formation of vee-grooves, and are reversible in the sense that they may be used as either right-hand or left-hand cutters.

The tee-slot cutter is one which has both axial and radial teeth. It is used, as its name signifies, to finish the tee slots in the beds, tables, and slides of machines generally, and more especially machine-tools.

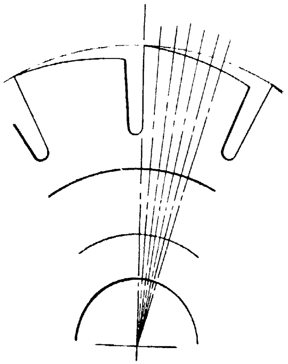


FIG. 102.—Profile shape of formed cutter teeth.

The side-and-face milling cutter also has both axial and radial teeth. If it is used as a slot or key-way milling cutter, it is generally of a standard width, and, as such, it is sometimes made with only axial face teeth, with its sides ground inwards towards the centre in order to provide side clearance, and so prevent the cutter from having any tendency to bend in the slot or keyway formed. It is sometimes set up in pairs, the two cutters being separated by

a distance piece or sleeve which is placed on the cutter arbor. Such a combination is known as a *straddle* milling cutter, and it may be used when it is necessary to mill two flat vertical and parallel faces on a work-piece at a definite distance from each other.

Formed Milling Cutters.—The teeth of formed milling cutters are of the backed-off or relieved type. The profile or outline of each tooth when viewed

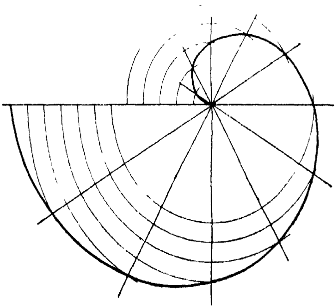


FIG. 103.—Archimedian spiral.

from the side should be that indicated in Fig. 102, the line which represents the outside of the tooth being in the form of an Archimedian or arithmetical spiral (Fig. 103), and the front cutting face of the tooth should always be radial. Only if these two conditions are satisfied will the original form of the tooth be maintained, and it is this maintenance of tooth-form which is claimed to be such a valuable characteristic of this type of milling cutter. Great care has, therefore, to be taken in connection with

the backing-off and grinding of these cutters, successive grindings always forming front cutting faces in radial planes, as indicated by the radial lines in Fig. 102. The backing-off (which includes the shaping and relieving of the teeth) is performed in special machines known as *relieving* or *backing-off* lathes, or in lathes equipped with relieving or backing-off attachments The grinding is generally done on universal tool and cutter-grinding machines with

Fig. 104.—Formed milling cutter.

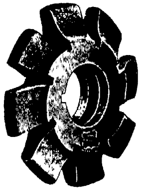


Fig. 105 —Gear-tooth milling cutter.

the aid of special fixtures to enable the front cutting face to be ground truly radial.

In Figs. 104 and 105 are illustrated two formed milling cutters, the first being a reamer-fluting cutter and the second an involute cutter for gear cutting. Fluting cutters for taps and twist-drills, and cutters for giving special shapes to machine parts, such as links, levers, and bars, are also of this type.

No clearance has to be ground on formed milling cutters, as is the case with fluted milling cutters, since the requisite clearance is given to the teeth in

a distance piece or sleeve which is placed on the cutter arbor. Such a combination is known as a *straddle* milling cutter, and it may be used when it is necessary to mill two flat vertical and parallel faces on a work-piece at a definite distance from each other.

Formed Milling Cutters.—The teeth of formed milling cutters are of the backed-off or relieved type. The profile or outline of each tooth when viewed

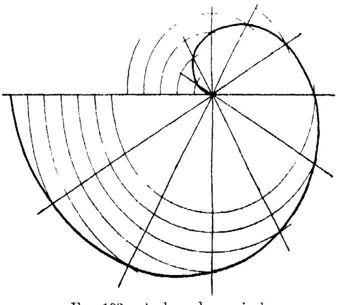


FIG. 103.—Archimedian spiral.

from the side should be that indicated in Fig. 102, the line which represents the outside of the tooth being in the form of an Archimedian or arithmetical spiral (Fig. 103), and the front cutting face of the tooth should always be radial. Only if these two conditions are satisfied will the original form of the tooth be maintained, and it is this maintenance of tooth-form which is claimed to be such a valuable characteristic of this type of milling cutter. Great care has, therefore, to be taken in connection with

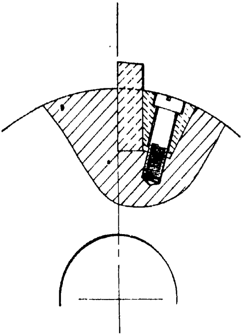


FIG. 107.—Inserted milling-cutter tooth.

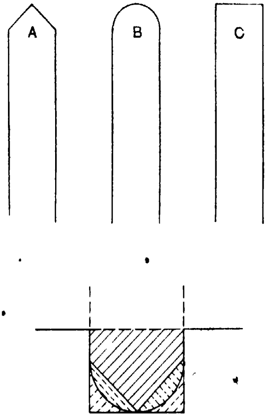


FIG. 108.—Profiles of inserted teeth of slitting saws.

against the back of the blade by the screw shown in the figure.

Large slitting saws are usually made with inserted teeth. It is found that, in connection with the cutting of the softer metals, and particularly those having fibrous structures, with slitting saws, the best results are obtained if the cutting elements are arranged in sets of three, the three blades of each set having different edge shapes, as shown at A, B, and

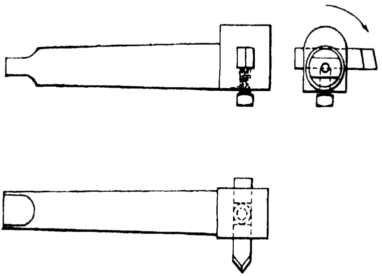


FIG. 109.—Fly milling cutter.

C in Fig. 108. The first shape of the three is in the form of a triangle, the second in the form of a semicircle, and the third in the form of a square. The amounts of metal removed by the three cutters respectively are indicated in the subjoined diagram of the figure.

The so-called fly-cutter, which is used when a very special shape has to be given to a small number of work-pieces, as in tool-rooms, is a type of formed cutter, though it is not usually made to maintain its shape exactly after a number of grindings. One

form of fly-cutter holder is shown in Fig. 109, whilst examples of shapes of fly-cutters are given in Fig. 110.

Milling-cutter Arbors.—All milling cutters which are provided with central holes have to be mounted on, and driven by, steel spindles or shafts, which are known as *arbors* generally. It is advisable not to call these elements *mandrels*, but to reserve this latter description for the shafts or bars upon which work-pieces are carried and driven for machining purposes.

The design of a milling-cutter arbor depends to a

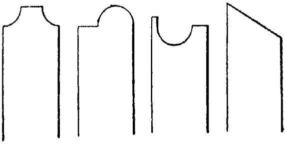


FIG. 110.—Profiles of fly-cutter teeth.

very large extent upon the design of the milling machine in which it is to be used, and also upon the design of the cutters to be driven on it. The former of these two conditions is so influential that it is the general practice of manufacturers of milling machines to make and supply cutter arbors to suit their machines, and it is usually found that the cutter arbors for one make of milling machine cannot be used in milling machines of other makes.

Solid milling cutters which are provided with central holes, such as plain milling cutters, are ordinarily mounted on horizontal arbors with tapered driving shanks which are socketed in the driving spindle of the milling-machine head. The outer end

of the arbor is supported either on a centre or in a bronze bushing, the latter method being the superior of the two; whilst the cutter is mounted on a parallel part of the arbor and held in its place there by means of a nut.

In Fig. 111 is represented one form of this type of milling-cutter arbor. S represents the tapered shank which is inserted in the tapered socket of the driving spindle of the milling machine, B represents the body on which the cutter is mounted, N represents the nut which is screwed on the body to hold the cutter in place, and J is the journalled end of the arbor which is inserted in a bronze bushing,

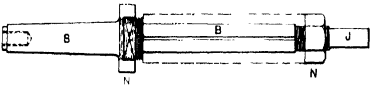


FIG. 111.—Milling-cutter arbor.

usually held in the overhanging arm of the machine. N_1 is another and larger nut which is used to withdraw the arbor from the spindle by being screwed up tightly against the nose of the spindle. On either side of the cutter there are placed movable sleeves or collars of various lengths on the body, so that the position of the cutter on the arbor is adjustable to a certain extent.

The shank of the arbor is drawn into the spindle-socket by means of a draw-in bolt, which runs through the driving spindle—this, of course, being hollow—and has its head bearing against the tail-end of the spindle, whilst its other end is screwed into the arbor. Before the nut N_1 can be used this draw-in bolt has to be screwed out of the end of

the arbor. In Fig. 112 is shown an arrangement whereby the spindle bolt B can be used to push the the arbor out of the spindle as well as to draw it in. In this case the bolt is provided with a collar below the head, and either face of the collar can be brought

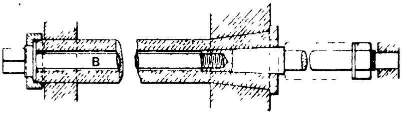


FIG. 112.—Method of expelling cutter arbor from spindle.

up against a fixed face, so that any further rotation of the bolt is bound to cause the arbor to move, either inwards or outwards as the case may be.

In Fig. 113 is illustrated a clutched form of cutter arbor, two parallel faces being formed on a collar on

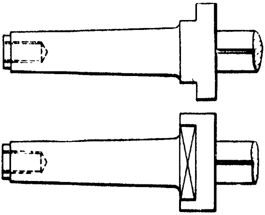


FIG. 113.—Clutched form of milling cutter arbor.

the arbor, these two faces working in conjunction with two corresponding faces on the inside of the nose of the driving spindle.

Another form of drive for this type of arbor involves the use of a tang at the end of the shank. The arbor in such a case is driven out of the spindle

by means of a drift. This form of drive is, however, not as much used as either of the above.

The drive between the arbor and the cutter when the arbor is of any of the above forms is usually a key drive, a plain frictional drive being reserved for

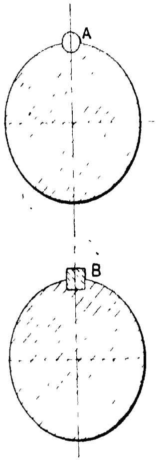


FIG. 114.—Forms of milling-cutter keys.

only those cases wherein the cutting is of the lightest description. In Fig. 114 are shown the two forms of key used. That shown at A is of circular section; that shown at B is of square section with the corners slightly rounded.

End and similar milling cutters are provided with tanged tapered shanks. Shell end mills have to be

mounted on special arbors, as shown in Fig 115. These may be tanged as represented, or they may be provided with a threaded hole at the end to take a draw-in bolt. In place of the projecting tongues to drive the shell, if the shell is built up, a key running the greater part of the length of the body is used.

Collets are used for the purpose of driving end and other shanked milling cutters when the shanks of the cutters are smaller than the spindle socket.

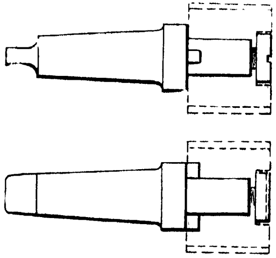


FIG. 115.—Arbor for shell end mill.

They are tapered internally and externally, the methods of driving and withdrawing them being practically the same as those which obtain in the case of the ordinary cutter arbor.

Numbers of Teeth in Cutters.—There is a difference in regard to this matter between English practice and American practice, the numbers of teeth in English-made cutters being generally greater than those in corresponding cutters made in America. The following formula will enable the number of

by means of a drift. This form of drive is, however, not as much used as either of the above.

The drive between the arbor and the cutter when the arbor is of any of the above forms is usually a key drive, a plain frictional drive being reserved for

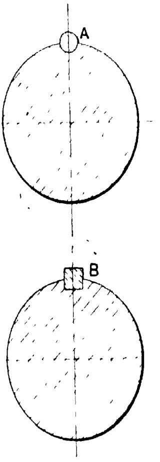


FIG. 114.—Forms of milling-cutter keys.

only those cases wherein the cutting is of the lightest description. In Fig. 114 are shown the two forms of key used. That shown at A is of circular section; that shown at B is of square section with the corners slightly rounded.

End and similar milling cutters are provided with tanged tapered shanks. Shell end mills have to be

As a rough guide, the following speeds may be taken as representative for plain-carbon steel cutters :—

For milling steel	. . .	25 to 40 feet per minute.
,, ,, cast iron	.	18 ,, 60 ,, ,,
,, ,, brass and bronze	.	80 ,, 100 ,, ,,

When high-speed cutters are used, these speeds may be increased by at least 50 per cent., and even 100 per cent. in some cases.

The question of working feeds of milling cutters cannot be dealt with simply, since so much depends upon the diameter of the cutter, the number of teeth in it, the stability of the milling machine, the cutting speed, and the nature of the material to be milled. Feeds as fine as $\frac{1}{8}$ inch per minute, and as coarse as 36 inches per minute, have been employed. The latter is, of course, very exceptional, and ordinary milling-cutter feeds very rarely exceed 12 inches per minute. The determining factor in every case appears to be the thickness of the chip which is removed by each tooth of the cutter.

The following feeds may be taken as fairly good average feeds for the majority of cases :—

On steel	. . .	1 to $1\frac{1}{2}$ inches per minute
,, cast iron	.	$1\frac{1}{2}$,, 2 ,, ,, ,,
,, brass and bronze	.	2 ,, 3 ,, ,, ,,

It should be observed that both speeds and feeds of milling cutters are influenced by the use of cooling and lubricating compounds, such as soluble-oil mixtures, soda and water mixtures, lard oil, and soft soap and water.

Direction of Feed.—This is a matter of some importance. The direction of the feed of a work-piece

should, wherever it is possible, be such that, when the work-piece and each tooth of the cutter meet, they are instantaneously moving in opposite directions. This condition is indicated in Fig. 116, in which the arrow C represents the direction of rotation of the cutter and the arrow W the direction of the feed movement of the work-piece; and it is one which can generally be realised when plain, angular, and formed milling cutters are in use, but which can be only partly realised in some cases when the milling cutters in use are end mills.

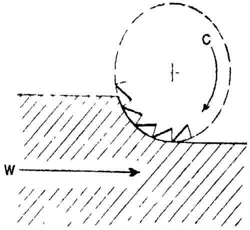


FIG. 116.—Direction of milling-cutter feed.

When this condition is satisfied, the cutting edge of each tooth glides into action as it were, and the duty of each tooth is gradually increased until its maximum value is reached just as the cutting edge is about to leave the work-piece. If, however, the cutter runs with the feed of the work-piece this state of affairs is reversed, and each tooth is subjected to a shock at the instant that it enters the work-piece, the duty of the tooth falling gradually from a maximum to zero. The reason for this is represented graphically in Fig. 117. In this figure, the sec-

tioned area represents the original shape of the metal removed by the tooth of a milling cutter under the conditions of depth of cut and feed indicated, D being the depth of cut, and F the *feed* of the work-piece per *tooth* of the cutter. If the tooth enters the work-piece at A, the thickness of the chip is practically nothing at the commencement of the cut, and increases gradually up to the time that the

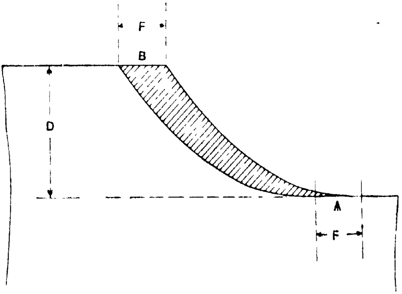


FIG. 117.—Diagram illustrating milling-cutter action.

tooth leaves the work-piece. On the other hand, if the tooth enters the work-piece at B, it begins to remove the thicker end of the chip, and at the instant that the tooth leaves the work-piece the thickness of the chip has become nothing.

Cases are not unknown wherein this matter has not been considered, with the result that either the teeth of the milling cutters have been stripped off or the cutter arbors have been broken, each of these results being accompanied by damage to the work-piece.

should, wherever it is possible, be such that, when the work-piece and each tooth of the cutter meet, they are instantaneously moving in opposite directions. This condition is indicated in Fig. 116, in which the arrow C represents the direction of rotation of the cutter and the arrow W the direction of the feed movement of the work-piece; and it is one which can generally be realised when plain, angular, and formed milling cutters are in use, but which can be only partly realised in some cases when the milling cutters in use are end mills.

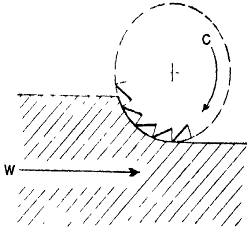


FIG. 116.—Direction of milling-cutter feed.

When this condition is satisfied, the cutting edge of each tooth glides into action as it were, and the duty of each tooth is gradually increased until its maximum value is reached just as the cutting edge is about to leave the work-piece. If, however, the cutter runs with the feed of the work-piece this state of affairs is reversed, and each tooth is subjected to a shock at the instant that it enters the work-piece, the duty of the tooth falling gradually from a maximum to zero. The reason for this is represented graphically in Fig. 117. In this figure, the sec-

respectively. It will be noticed that P is ahead of O. The two arrows indicate the direction in which the axes of the cutters move *with respect* to the work-piece, the actual movement in the machine being usually given to the work-piece. Both cutters leave the work-piece when their axes O_1 and P_1 are in the same vertical plane (represented by the vertical line A_1, P_1, O_1), the smaller cutter having travelled a distance D_1, *with* respect to the work-piece, whilst under the same circumstances the larger cutter has had to travel a distance D. Now the time occupied in each case is directly proportional to the distance travelled, since the two rates of feed are equal, therefore it follows that it is more economical to employ a cutter of small diameter than one of large diameter, the percentage gain being determined by means of the following formula.—

$$\text{Percentage gain} = \frac{D - D_1}{D} \times 100 \quad . \quad (4)$$

From this it will be seen that the smaller the value of D, the greater is the percentage gain. In other words, this gain is more pronounced on short work-pieces than on long ones.

The diameter of a milling cutter should also be kept small for the reason that with a small-diameter cutter the torque or twisting moment on the cutter arbor is less than when a large-diameter cutter is used, if the general conditions of cutting are identical in the two cases. This point is demonstrated in Fig. 119, in which F represents the tangential cutting force (assumed to be the same in

the two cases) and R and R_1 the radii of the large and small cutters respectively. The torque or twisting moment in the case of the large cutter is $F \times R$ and is obviously greater than that of the small cutter, which is only $F \times R_1$. The importance of the torque to which a milling-cutter arbor is subjected lies in the twofold fact that the torque determines the maximum stresses which are induced in the arbor and key and also the tendency

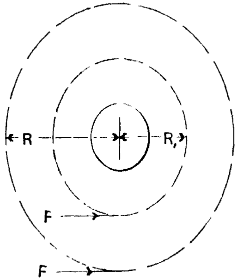


FIG. 119. Diagram of cutting forces in milling.

on the part of the arbor to twist out of its socket in the driving spindle.

Plain Milling Operations.—These are distinguished by the fact that they are performed on the ordinary plain horizontal and vertical milling machines. They consist chiefly of operations for the production of flat surfaces and simple cylindrical surfaces.

In Fig. 120 is illustrated the milling of the flat faces of a hexagonal nut by means of a plain milling cutter. The nut is mounted on a mandrel which is

placed between plain indexing centres, the dividing of the circle of the work-piece into six equal parts

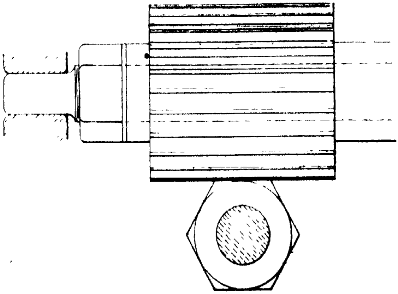


FIG. 120 Milling flats on hexagonal nut.

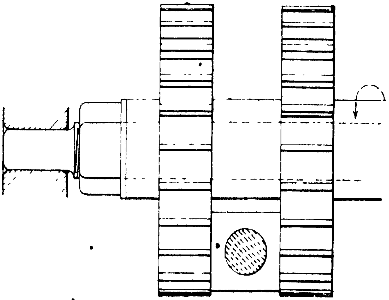


FIG. 121.- Straddle-milling square nut or head

being done by means of the indexing plate or wheel on the indexing head. The milling of such nuts is done more economically if the mandrel is made to

take a number of them instead of only one at a time.

In Fig. 121 is indicated the use of two side and face milling cutters in the form of a *straddle* mill, by means of which two opposite faces of a square nut or square bolt head are being milled. In the case shown the inside faces of the cutters are at work on the outside faces of the nut or bolt head,

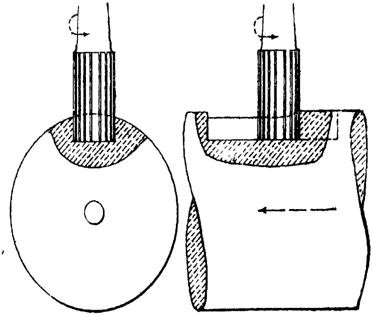


FIG. 122.—Keyway-milling.

but straddle mills can be employed equally well for the milling of the inside faces of work-pieces by the outside faces of the cutters.

The milling of a keyway in a shaft by means of an end milling cutter is represented in Fig. 122. The two arrows indicate the direction of rotation of the cutter and the direction of the feed of the work-piece respectively. In Fig. 123 is shown a method of milling a keyway in a shaft by means of a slot mill or side and face milling cutter. The

placed between plain indexing centres, the dividing of the circle of the work-piece into six equal parts

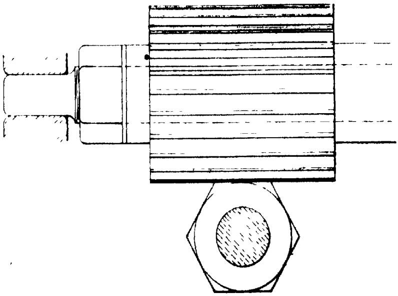


FIG. 120 Milling flats on hexagonal nut.

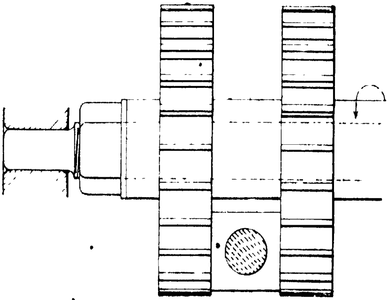


FIG. 121.- Straddle-milling square nut or head

being done by means of the indexing plate or wheel on the indexing head. The milling of such nuts is done more economically if the mandrel is made to

In the two views of Fig. 124 are indicated the two operations which are usually performed in connection with the formation of a tee-slot. The body of the slot is formed by means of an end milling cutter, whilst the lower cross portion is formed by means of a special tee-slot mill.

A gang mill is made up of a number of different cutters which are of such forms and arranged together in such a manner that they will mill a work-

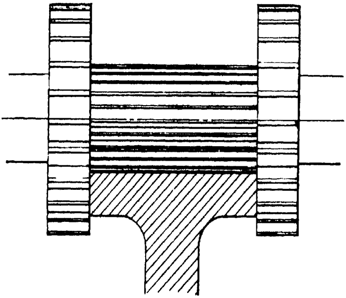


FIG. 125.—Use of gang mill.

piece to a definite shape. Both fluted and formed milling cutters are used in the building up of gang mills, in some cases there being both types side by side. In Fig. 125 is illustrated the use of a gang mill of a comparatively simple construction. It consists of a plain milling cutter with a side and face cutter on each side of it, and is used to form machine ways or guides.

The use of an end milling cutter in connection with the formation of a cylindrical surface is illus-

trated in Fig. 126. The work-piece in this case is mounted on a circular milling attachment, and arranged to revolve in the same direction as the cutter, but at a much lower speed, since its speed is also its feed. This is an example of vertical milling, as is that shown in Fig. 122.

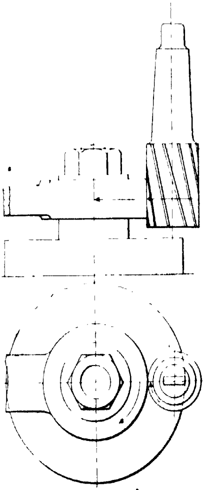


FIG. 126.—Forming by means of end mill.

Another example of vertical milling is indicated in Fig. 127. In this case the inclined faces of a dove-tail guide or slide are milled by means of an angular milling cutter of the same angle as that between the inclined faces to be milled and the horizontal.

The Universal Dividing Head and Its Uses. — The universal or spiral dividing head is an essential element of the universal milling machine. It is built in a number of different designs, but the essential feature of each design is a worm-gear, usually having a fixed ratio of 40 to 1, which connects the indexing handle to the spindle of the head through

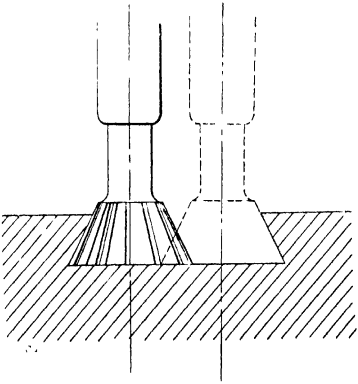


FIG. 127.—Milling dove-tail groove.

which the work-piece is rotated in the indexing or dividing operations. The indexing handle has thus to be rotated forty times in order to give one complete turn to the spindle and work-piece, the final position of the handle being identical with its initial position.

The two primary functions of the universal or spiral dividing head are: (1) the dividing of the circle of a work-piece into a number of either equal

or unequal parts, and (2) the rotating of a work-piece simultaneously with the feed movement of the table of the machine, so as to admit of a helical groove or grooves being milled in it.

Equal and Unequal Spacing.—In the majority of the instances of the use of the dividing head, the circle or periphery of the work-piece has to be divided into a number of equal parts, as indicated

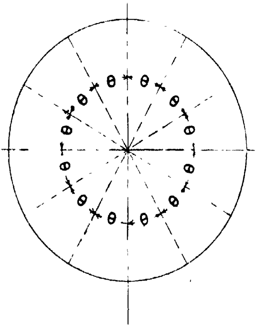


FIG. 128.—Illustrating equal spacing.

in Fig. 128. This is known as *even* or *equal spacing*. In the other cases, the parts into which the circle of the work-piece is divided are not equal. This is known as *unequal spacing*, and is based on a slightly different principle from that which underlies equal spacing.

Indexing Methods.—These may be divided into *direct* and *indirect* methods. Of the former there is only one, namely, the simple method, whilst of

the latter there are the simple, compound, approximate compound, and differential methods.

The Simple Direct Method of Indexing.—When the circle of a work-piece has to be divided into a number of parts which is an aliquot part or submultiple of 24, such as in the cases indicated in Figs. 131-134, this method may be employed. It involves the use of an indexing plate on the spindle of the head, this plate having twenty-four holes spaced equidistantly round a circle centred at the axis of the spindle, and working in conjunction with a stop pin in the head so arranged that it can be made to enter any hole in the circle that may be opposite to it. By this method, 2, 3, 4, 6, 8, 12, and 24 equal divisions can be indexed for quite easily and expeditiously.

The Simple Indirect Method of Indexing.—This is the method of indexing which is the most commonly used. It is based directly upon the ratio of the worm gearing in the head, use being made of the indexing handle which is mounted on the worm shaft, it being necessary to give to this handle a definite movement for each division of the circle of the work-piece. The magnitude of this movement will depend upon the number of equal parts into which the circle of the work-piece has to be divided, and also upon the worm-gear ratio, that is, 40 to 1. Thus, if N = the number of equal divisions required in the circle of the work-piece, and n = the number of turns of the indexing handle corresponding to each division of the work-piece circle, we have that—

$$n = \frac{40}{N} \quad \ldots \quad (5)$$

This is the fundamental formula for this method.

Now, n may be either an integer, such as 4, a mixed number, such as $3\frac{1}{13}$, or a proper fraction, such as $\frac{10}{49}$, from which it will be seen that it is necessary to be able to obtain fractional turns of the handle, as well as whole or complete revolutions. To assist in the obtainment of fractional turns, indexing plates (Fig. 129) are used, these being plates which are provided with a number of concentric circles of small holes, in any one of which a locking pin in the head of the indexing handle can be inserted. Usually there are eighteen circles of holes provided, and the numbers of holes in the various circles range variously from fifteen to forty-nine, from twenty-one to forty-nine, and from twenty-six to forty-nine, with, of course, certain omissions in each case. Ordinarily, forty-nine is the highest number of holes furnished, so that, under such circumstances, it is not possible to index for prime numbers above forty-nine.

To illustrate the application of this method of indexing, we will take the case of a work-piece whose periphery has to be divided into, say, eighty-four equal parts. For this value of N, we find that, by means of expression (5), the value of n is $\frac{40}{84}$, or $\frac{10}{21}$ when it is reduced to its lowest terms. This means that a $\frac{10}{21}$st part of a whole turn of the indexing handle is required. Now, if we have a 21-hole circle on the indexing plate, we can use this directly, ten holes in this circle giving the required fractional turn. If we have not a 21-hole circle, we shall have

a 42-hole circle in place of it, and twenty holes in this circle will give the $\frac{10}{21}$st part of a whole turn, since $\frac{20}{42} = \frac{10}{21}$.

The work of counting the required number of holes in the selected circle would be exceedingly tedious if

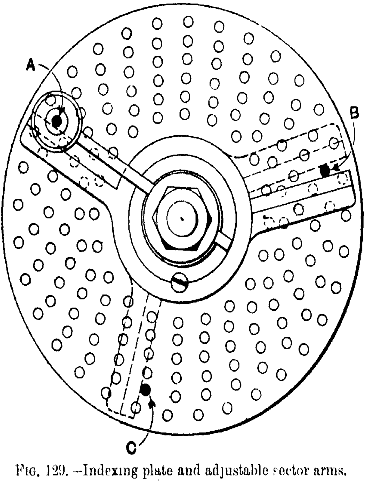


FIG. 129.—Indexing plate and adjustable sector arms.

it had to be done for each division of the work-piece. A device which consists of two adjustable sector arms (Fig. 129) working over the face of the indexing plate is, therefore, invariably used to avoid the necessity of counting the number of holes each time. The sector arms are initially set to include between them one more than the number of holes obtained

by the calculation, since the calculated result does not include the hole from which the pin in the indexing handle moves, whereas this is *always* situated between the sector arms, as is indicated in Fig. 129, which also shows two consecutive positions of the sector arms, the holes A, B, and C being those into which the pin is consecutively inserted. If the spaces between the holes are counted instead of the holes themselves, then the number counted should be the same as the number obtained by calculation.

A list of the indexing-plate circles and the number of spaces on these circles for a series of numbers of equal divisions is given in the Appendix in Table IV.

The Compound Method of Indexing.—This method involves the compounding of two fractions, either by addition or subtraction, in order to obtain the fractional turn required. One fraction represents the movement of the indexing handle with respect to the plate, whilst the other represents the common movement of the handle and plate (locked together) with respect to some fixed point in the dividing head. Thus—

$$n = \frac{40}{N} = F_1 \pm F_2 \quad . \quad . \quad . \quad (6)$$

where F_1 = the fractional turn of the handle alone, and F_2 = the common movement of the handle and plate.

The use of this method is limited, though it can be employed for the indexing of one or two rather useful numbers on the ordinary type of universal dividing head.

To illustrate the use of this method we will consider the case of 63 equal divisions. This number cannot be indexed for by means of the simple indirect method, when the usual numbers of holes are provided in the indexing-plate circles, since 40 and 63 are numbers which are prime to each other, and $\frac{40}{63}$ is a fraction which is reduced to its lowest terms. This fraction, $\frac{40}{63}$, however, is equal to $\frac{49-9}{63}$, which, in turn, becomes $\left(\frac{49}{63}-\frac{9}{63}\right)$, and this, by reduction to lowest terms, is resolved into $\left(\frac{7}{9}-\frac{1}{7}\right)$. The first fraction equals either $\frac{21}{27}$ or $\frac{28}{36}$, and the second $\frac{7}{49}$, each of these two combinations giving the required result. In an actual case in which a gear-wheel blank had to be divided into 63 equal parts, the compound fraction $\left(\frac{21}{27}-\frac{7}{49}\right)$ was utilised, the first fraction being obtained from the front of the indexing plate, and the other from the back.

The Approximate Compound Method of Indexing.—This method is of universal application, but its use involves the utilisation of two special indexing plates, having either 101 and 100 holes, or 100 and 99 holes, respectively, and these have to be specially made.

The Differential Method of Indexing.—In this method of indexing (which was introduced by the

Brown & Sharpe Co. of America to enable numbers outside the scope of the simple indirect method to be indexed for) the indexing plate is not fixed in position, but has given to it a rotation which is simultaneous with, and proportional to, the movement of the indexing handle. Consequently, the method can only be applied to dividing heads which are so designed that it is possible to connect the spindle of the head to the indexing plate by means of positive toothed gearing, to enable the former to drive the latter directly. In such cases, the indexing plate makes a definite number of turns for each complete turn of the work-piece or head-spindle, that is, for each 40 complete turns of the indexing handle with respect to any fixed point on the head, so that the indexing handle makes either more or less than 40 turns *relatively to the indexing plate* per turn of the work-piece. This latter number, whatever it may be, is the one which is used in connection with this method in place of the 40 used in expressions (5) and (6). The fundamental formula in this case is—

$$n = \frac{40 + R}{N} \quad . \quad . \quad (7)$$

where R is the number of turns of the indexing plate per revolution of the work-piece, and is a positive quantity when the indexing handle and plate revolve in opposite directions, and a negative quantity when they revolve in the same direction. The value of R is the ratio of the external change-wheel gearing which is employed to connect the head-spindle to the indexing plate, and its sign is determined solely by the number of wheels in this gearing. The

quantity (40 + R) is usually known as the "index spacing number".

By means of this method all numbers up to and including 382 can be indexed for, unless they are provided for by the simple indirect method

Unequal Spacing.—When the parts into which the circle or periphery of a work-piece has to be divided are unequal, the number of parts cannot be made use of directly when determining the number of turns of the indexing handle per division of the work-piece circle. In this case, use has to be made of the angle subtended by each part at the centre of the work-piece circle. Suppose that this equals θ. Then—

$$n = \frac{\theta}{9} \qquad . \quad (8)$$

Helical Work on the Universal Milling Machine.—In connection with the cutting of helices on the universal milling machine, it is necessary to connect, by means of toothed gearing, the table feed-screw and the worm-shaft of the dividing head, so that two simultaneous motions, normal to each other, are given to the work-piece. These two motions are a translatory motion obtained directly from the table of the milling machine, and the rotatory motion obtained through the dividing head; they are indicated in Fig. 130.

The fundamental formula for the computation of the numbers of teeth in the change-gear wheels to be employed is—

$$R_1 = \frac{40 \times \text{lead of table feed-screw}}{\text{lead of helix to be cut}} \qquad (9)$$

where R_1 is the ratio of the product of the numbers of teeth in the driving wheels to the corresponding product for the driven wheels. In the ordinary universal milling machine, the lead of the table feed-screw is either $\frac{1}{4}$ in. or $\frac{1}{2}$ in., so that we have, in such cases—

$$R_1 = \frac{10 \text{ or } 20}{\text{lead of helix to be cut}} \quad . \quad (10)$$

The denominator of the right-hand side of expression (8) is known as the "lead of the machine,"

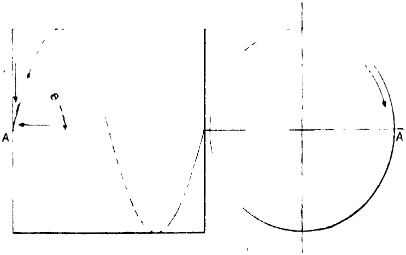


FIG. 130.—Helix.

and has, ordinarily, a value of 10 or 20, as expression (10) shows. The significance of the expression "lead of the machine" is this: When the ratio of the change-wheel gearing is unity, the lead of the helix that is cut equals the lead of the machine.

The hand of the helix to be cut in any given case determines the number of change-gear-wheels, that is, whether an idler or intermediate gear-wheel shall or shall not be employed.

In addition to gearing up the dividing head to give the required lead of helix, it is necessary to

swing the table of the milling machine through an angle about a vertical axis. This is the angle θ of Fig. 130. It is known as the "angle of the helix," and its magnitude depends solely on the diameter of the cylinder on which the helix is traced and the lead of the helix. Its values for a number of

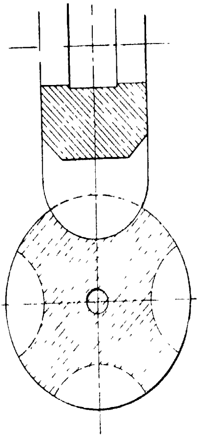
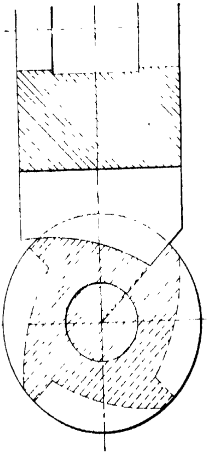


FIG. 131.—Screw-tap fluting.

ratios of lead of helix to diameter of cylinder are given in Table V. of the Appendix.

Fluting Operations in the Milling Machine.—In Figs. 131 and 132 are represented the conditions which obtain when screw taps are fluted in the milling machine. In the cases shown, the taps have four flutes, but the principle is precisely the same in those cases wherein the taps have only three

flutes. In Fig. 131 the fluting cutter shown is a formed convex cutter, and forms flutes of a circular shape, the cutter shown in Fig. 132 is an angular cutter (either formed or fluted), and forms angular flutes, which are sometimes known as "hook flutes".



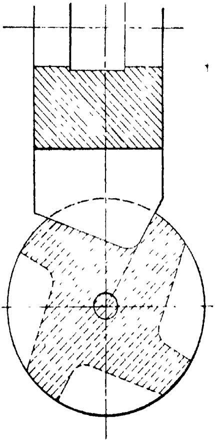


FIG. 132.—Screw-tap fluting. FIG. 133.—Boring-tool fluting.

The form of fluting cutter used on four-lipped boring tools is indicated in Fig. 133, whilst a twist-drill fluting cutter is represented in Fig. 134. Both these cutters are of the formed type.

The fluting of reamers and milling cutters differs from the above in so far as the number of flutes to be milled is in this case always greater than four

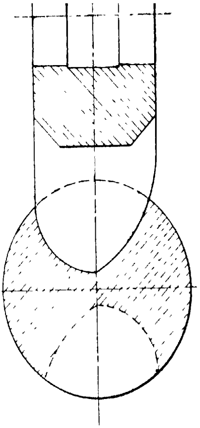


FIG. 134.—Twist-drill fluting.

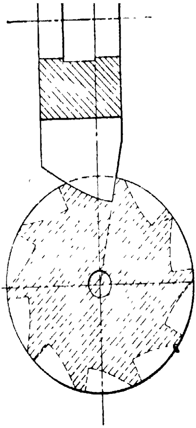
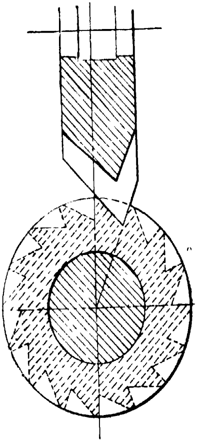
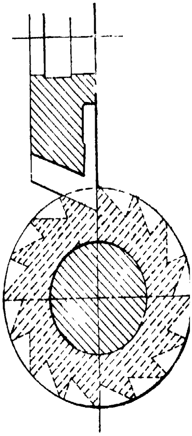


FIG. 135.—Reamer fluting.





and very rarely less than eight. The fluting of a reamer is indicated in Fig. 135. In this case the cutter employed is of the formed variety. The fluting of a plain milling cutter with helical teeth is represented in Fig. 136. In this case the cutter is a double-angle fluted cutter. The corresponding

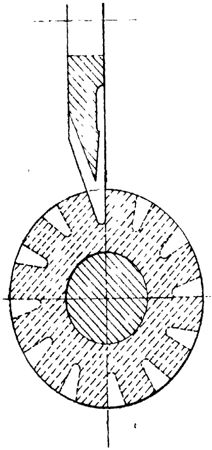


Fig. 138.—Cutter for straight gashing.

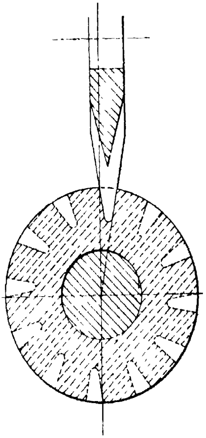


Fig. 139.—Cutter for helical gashing.

case of a single-angle fluting cutter is shown in Fig. 137, this form of cutter being suitable only for the formation of milling-cutter teeth with straight cutting edges.

Formed cutters are not fluted, but are instead *gashed*. The gashing of a formed cutter with straight teeth is represented in Fig. 138, whilst that

of a formed cutter with helical teeth, such as a worm hob, is represented in Fig. 139.

In all cases of fluting and gashing, the dividing out of the blanks is done by means of the simple indirect method of indexing, since the number of grooves or gashes to be milled out is never large and nearly always an even number.

CHAPTER IV.

GEAR-WHEEL CUTTING.

THE increase of running speeds which has been made in machinery generally within recent years has resulted in the almost general abandonment, except in one or two special departments of engineering, of cast toothed-gearing with its inaccuracies, in favour of machine-cut gearing with its high degree of accuracy of size and shape.

The cutting of toothed wheels is usually effected by means of either the planing or shaping or the milling process, the former in some instances being the more efficient of the two, though, in the majority of instances, it is the milling or a similar process which is the more commonly employed.

Spur Gear-wheels.—Ordinary spur gear-wheels are cut by the milling process on the universal milling machine, the automatic gear-cutting machine, and the automatic gear-hobbing machine; by the planing process, on the automatic gear-planing machine; by the shaping process, on the automatic gear-shaper.

In the case of the first and second methods, milling cutters of the straight-gashed formed type, as shown in Fig. 105, are employed to give tooth-curves or odontoids of either the involute or the

cycloidal form, the cutter (apart from its rotation) having a simple straight line movement with respect to the wheel blank and parallel to its axis.

Involute Tooth-form.—The involute form of tooth-curve is the commoner of the two, and is sometimes known as the single-curve form, since it consists of one curve which extends from the point of the tooth to the root, as indicated in Fig. 140. The involute curve is not theoretically a circular arc, but in actual practice circular-arc approximations to the involute curve are made when setting out templates

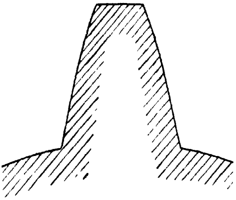


FIG. 140.—Involute tooth-form.

and tools for the manufacture of gear-milling cutters, use being made of those arcs which most nearly agree with the theoretical involute curves. Theoretically the tooth-shapes for wheels having different numbers of teeth are different, but in practice it is found that the same tooth form will serve for a series of wheels having consecutive numbers of teeth, so that one cutter will form the teeth of a series of wheels. In the whole set of involute cutters for numbers of teeth ranging from twelve to a rack (which may be regarded as a wheel having an infinite number of teeth), there are usually only eight

cutters for each pitch, these being numbered as follows

No. 1,	which will cut wheels having from	135 teeth to a rack.		
,, 2,	,, ,,	55 teeth	to 134	teeth.
,, 3,	,, ,,	35	,, 54	,,
,, 4,	,, ,,	26	,, 34	,,
,, 5,	,, ,,	21	,, 25	,,
,, 6,	,, ,,	17	,, 20	,,
,, 7,	,, ,,	14	,, 16	,,
,, 8,	,, ,,	12	,, 13	,,

For greater precision, sometimes cutters represented by half-numbers are used, these being as indicated below

No. 1½,	which will cut wheels having from	80	to 134	teeth.
,, 2½,	,, ,,	42	,, 54	,,
,, 3½,	,, ,,	30	,, 34	,,
,, 4½,	,, ,,	23	,, 25	,,
,, 5½,	,, ,,	19	,, 20	,,
,, 6½,	,, ,,	15	,, 16	,,
,, 7½,	,, ,,	13		

Cycloidal Tooth-form.—This form consists of two curves, for which reason it is sometimes referred

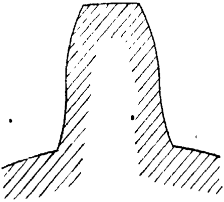


FIG. 141.—Cycloidal tooth-form.

to as the double-curve form (Fig. 141). Unless, however, it is accurately reproduced on the teeth of gear-wheels, the teeth of meshing or engaging wheels

will not work satisfactorily together, for which reason for ordinary work the involute form is preferred.

In a set of cycloidal cutters for numbers of teeth ranging from twelve to a rack, there are twenty-four, the individual cutters being designated by the letters of the English alphabet as under —

Cutter	A,	which will cut	wheels having	12			teeth.
,,	B,	,,	,,	13	,,		
,,	C,	,,	,,	14	,,		
,,	D,	,,	,,	15	,,		
,,	E,	,,	,,	16	,,		
,,	F,	,,	,,	17	,,		
,,	G,	,,	,,	18	,,		
,,	H,	,,	,,	19	,,		
,,	I,	,,	,,	20	,,		
,,	J,	,,	,,	21	to	22	teeth.
,,	K,	,,	,,	23	,,	24	,,
,,	L,	,,	,,	25	,,	26	,,
,,	M,	,,	,,	27	,,	29	,,
,,	N,	,,	,,	30	,,	33	,,
,,	O,	,	,,	34	,,	37	,,
,,	P,	,,	,,	38	,,	42	,,
,,	Q,	,,	,	43	,,	49	,,
,,	R,	,,	,,	50	,,	59	,,
,,	S,	,,	,,	60	,,	74	,,
,,	T,	,,	,,	75	,,	99	,,
,,	U,	,,	,,	100	,,	149	,,
,,	V,	,,	,,	150	,,	249	,,
,,	W,	,,	,,	250 or more			
,,	X,	,,	,,	rack.			

Dimensions of a Spur Gear-wheel.—In connection with machine-cut spur gear-wheels it is generally the diametral pitch which is employed as the basis of the leading computations, since its use leads to more definite values of the other dimensions of the wheels.

In Fig. 142 are indicated the principal dimensions of a spur gear-wheel from the view point of tooth-cutting. D_o is the outside or point diameter of the wheel, or the diameter of the blank ; D_p is the pitch diameter, or the diameter of the pitch circle ; D_r is the

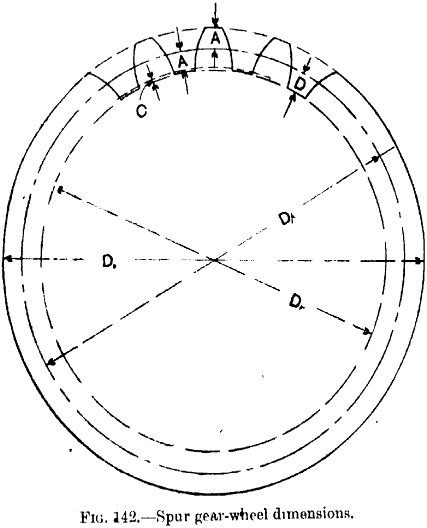


FIG. 142.—Spur gear-wheel dimensions.

inside, root, or bottom diameter of the wheel ; A is the tooth addendum ; D is the tooth dedendum ; C is the root or bottom clearance ; and (A + D) is the whole depth of the tooth-space or the whole height of the tooth.

If P_d is the diametral pitch and N is the number of teeth to be cut in the blank, we have that—

$$D_p = \frac{N}{P_d} \quad . \quad . \quad . \quad (11)$$

$$P_d = \frac{N}{D_p} \quad . \quad (12)$$

$$N = P_d \times D_p \quad . \quad (13)$$

$$D_o = D_p + \frac{2}{P_d} \quad . \quad . \quad (14)$$

$$= \frac{N + 2}{P_d} \quad (15)$$

$$A = \frac{1}{P_d} \quad . \quad . \quad . \quad (16)$$

$$C = \frac{0.1571}{P_d} \quad . \quad (17)$$

$$D = \frac{1.1571}{P_d} \quad (18)$$

$$\text{and } (A + D) = \frac{2.1571}{P_d} \quad . \quad (19)$$

By means of these formulæ, the diameter of the blank (required for the turning operations) and the whole depth of cut (required for the tooth-forming operations) are readily obtained. The quantity $\frac{1}{P_d}$ may be called the pitch module. In Table VI. of the Appendix are given the values of the addendum, the dedendum, the root clearance, and the whole depth of the tooth-space for diametral pitches ranging from 1 to 32.

If the circular pitch is the one used, the whole depth of the tooth-space is obtained by dividing the circular pitch by $\frac{\pi}{2}$ (1·571) and adding thereto one-twentieth part of the circular pitch.

Block Indexing.—In connection with the cutting of spur gear-wheels on the automatic gear-cutting machine, the wheel-blanks are automatically indexed. To reduce distortion of the blanks as the result of local heating due to cutting, a method of indexing known as *block indexing* is often resorted to. In this method, instead of indexing for consecutive tooth-spaces, the indexing is done in blocks or series, and the blanks have to be revolved several times before all the tooth-spaces have been cut out. In figuring out the number of divisions to have in each block or series, it is necessary to see that the number of teeth to be formed in the blank and the number of teeth in the block are prime to each other, that is, that they do not contain any common factor. If they are not prime to each other, then it will not be possible to cut all the teeth in the blank without altering the indexing arrangements.

By way of example, we will consider the case of a spur gear-wheel to have, say, 65 teeth. If we set up the indexing apparatus of the machine so that there are, say, 6 teeth in the block, we shall be able to cut all the 65 teeth, the blank having to be revolved six times to enable this to be done. Suppose, however, that we set up the machine with, say, 5 teeth in the block. Then we shall find that, at the end of the first revolution of the blank, we are exactly at the starting point with only 13 out of the 65 tooth-spaces formed, and that, to alter the relative position of the cutter to the blank, the latter has to be revolved by hand.

Spur Gear-wheel Hobbing.—In this process, which in principle is a milling process, the cutting

tool is in the form of a screw, gashed to form cutting edges, and known as a hob or hobbing cutter. The action of this cutter is such that no indexing in the ordinary sense of the term is necessary, the wheel-blank having a rotatory motion simultaneous with the rotatory motion of the cutter. Simultaneous with these two motions is the feed motion, this latter being given, in some cases to the cutter, in others to the blank, but the conditions of working are generally such that the whole of the teeth for their entire length are formed at one setting of the machine. The cutter has ordinarily to have a slight inclination given to its axis. By this method the tooth-form is generated.

Spur Gear-wheel Planing. The cutting tool in this process is either shaped, as for milling, so that the tooth-form is simply and directly reproduced from the tool, or arranged like a toothed-rack, the cutting tool in this case generating the tooth-form, as in the case of the hobbing method, but on a slightly different principle. There are three motions in this case. the rotation of the wheel blank; the slight longitudinal motion of the rack cutter; and the main cutting motion of the cutter.

Spur Gear-wheel Shaping.—In the shaping process the cutting tool is in the form of a toothed wheel, which is accurately made and finished to size. This is ground so that the outline of each tooth, in an end plane of the cutter, is a cutting edge. The principle underlying this method is not very different from that which obtains in the case of the planing method. There are three motions in this case: the rotation of the wheel blank; the main

cutting motion of the cutter; and the rotation of the cutter.

Helical and Spiral Gear-wheels.—These are toothed wheels, the tooth-elements of which are helical, as distinct from the straight, axial tooth-elements of the spur gear-wheels. Helical wheels differ from spiral wheels only in their use, meshing wheels of the former class always having their axis parallel to each other, whereas the axes of those of the latter class are inclined to each other at any angle up to 90°. Wheels of both classes are chiefly cut by the milling process on the universal milling machine, the gear-milling machine, and the automatic gear-hobbing machine, and by the planing process.

When the universal milling machine is employed for the cutting of these wheels, an ordinary formed gear-milling cutter is used, the axis of the blank (and therefore the table of the milling machine) being swung through an angle equal to the angle of the tooth-helix, that is, the angle θ indicated in Fig. 143. The dividing head has to be geared up to the longitudinal feed-screw of the table so as to give the required lead of the tooth-helix, the ratio of the gearing to be employed being calculated by means of expression (9) of the previous chapter.

In the gear-milling process, an end mill of the form shown in Fig. 144 is employed, this being guided in a helical direction over the wheel-blank.

The cutter in the case of the gear-hobbing method has its axis inclined at a greater angle to the horizontal than is the case in spur gear-wheel hobbing, the difference between the two inclinations being equal to the angle of the tooth-helix.

Bevel Gear-wheels.—These wheels, which have their teeth formed on the surface of a truncated cone, are cut in the universal milling machine and in the bevel gear-wheel planer. In the former case a formed gear milling cutter, about 0·005 inch narrower than the corresponding cutter for spur

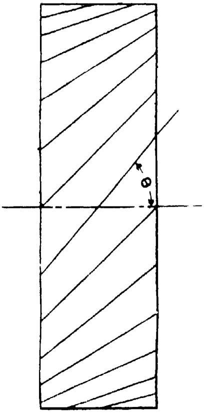


FIG. 143.—Angle of tooth-helix.

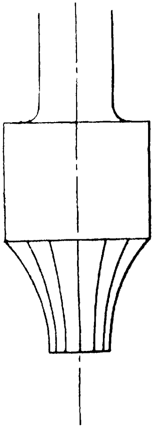


FIG. 144.—Formed gear-cutter.

gear-wheels, is used. The wheel-blank is set up at an angle to the horizontal in the dividing head, and central with respect to the cutter, so that a groove of uniform width at its base (Fig. 145) is cut. The blank is then turned about its own axis through a small angle to the right and bodily to the left so that the volume of metal represented by the shaded triangular area in Fig 146 can be removed by

feeding the cutter again through the blank. The corresponding volume on the other side of the space is removed by running the cutter through the blank with the latter in the position shown in Fig. 147, the volume removed in this case being represented by the shaded triangular area in the figure This method is only an approximate one,

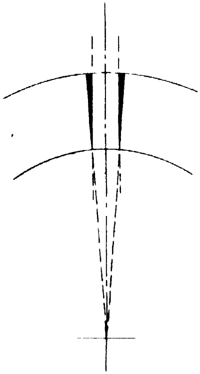


FIG. 145.—Bevel gear-wheel cutting.

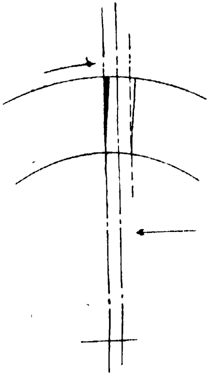


FIG. 146 Bevel gear-wheel cutting.

and is not suitable in those cases where the wheels have to run at very high speeds. In those cases, the planing method is resorted to, the transference and reduction of the shape of a former or copy plate being the principle underlying this method.

This latter method is the one which is largely employed in connection with the cutting of the teeth of skew bevel wheels.

Worm Gear-wheels.—The teeth of these wheels can be formed by either fixed-curve rotary gear

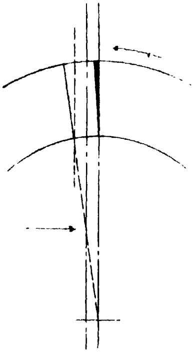


FIG. 147.—Bevel gear-wheel cutting.

cutters or worm hobs. The best wheels are cut by means of the latter form of cutter on automatic

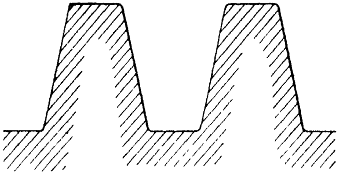


FIG. 148. Section of worm thread.

gear-hobbing machines, though the universal milling machine can also be used for this purpose.

Worms.—These, whether of the single or multi-

threaded form, can be cut in the lathe or in a special thread-milling machine. The latter machine is generally more suitable than the lathe for rapid and economical production.

The usual form of the thread of a worm is indicated in Fig. 148, the flanks or sides of the thread being straight, with an included angle between them of 29°, though sometimes an angle of 30° is adopted. The difference between the two is ordinarily negligible.

CHAPTER V.

LATHE METHODS AND OPERATIONS.

LATHE methods and operations differ considerably according to the types of machine in connection with which they have to be adopted. Methods and operations which are suitable on, say, turret lathes in connection with quantity production are unsuitable and, in many cases, impossible on engine lathes which are general-purpose machines.

1. **Engine-lathe Methods.**—In the engine or centre lathe the best method of driving a work-piece depends upon the shape and size of the work-piece and the nature of the operation to be performed upon it. A work-piece may be driven between the centres, gripped in a chuck or collet, or mounted on a face-plate or in a turning fixture.

Centring Work-pieces.—Several methods of locating the position of the centre of the end section of a work-piece have already been dealt with. There is, however, one to which no reference has yet been made. That is the bell centre punch method. By means of the bell centre punch it is possible to locate the position of the centre of the end of a rod, bar, or shaft, and to fix it by means of a centre punch mark at the same time. There are several forms of bell centre punch; two are indicated in Figs. 149

and 150. The design and use of these punches are obvious.

There is, however, one point in connection with their use that needs to be emphasised, and that is in connection with the centring of the ends of bars

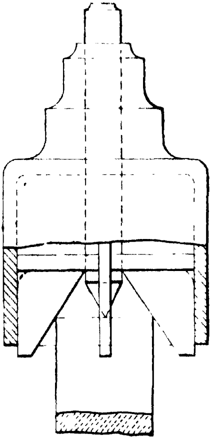


FIG. 149.—Bell centre-punch.

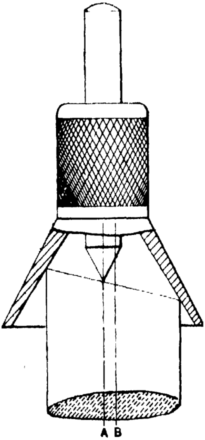


FIG. 150.—Use of bell centre-punch.

which are not square, as shown in Fig. 150. As will be seen from the figure, if the bell is placed on the bar so that its axis (A) is parallel to that of the bar (B), the punch will not locate the position of the centre of the end of the bar. It will much more nearly do this if the axis of the bell is disposed at right angles to the end of the bar, as will be seen

by a comparison of Figs. 150 and 151. In each case the bell will not rest firmly on the end of the bar, owing to the elliptical form of the end and the conical surface of the punch.

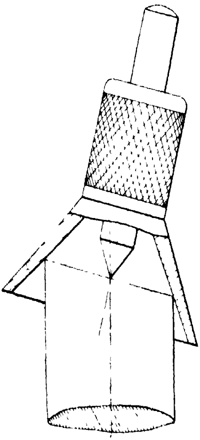


FIG. 151.– Use of bell centre-punch.

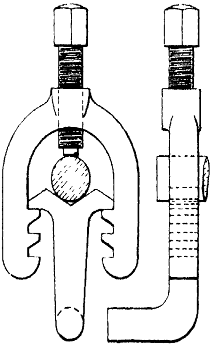


FIG. 152.—Adjustable screw carrier.

Driving Work-pieces between the Centres.—This is done mainly by means of carriers, of which there are two principal types, namely, screw carriers and clamp carriers. Examples of the former are given in Figs. 152 and 153, whilst examples of the latter type are shown in Figs. 154 and 155. The principal difference between the two types is in regard to the manner in which the work-piece is

gripped in the carrier, and to the strength of the grip. In each case the hold is simply a frictional

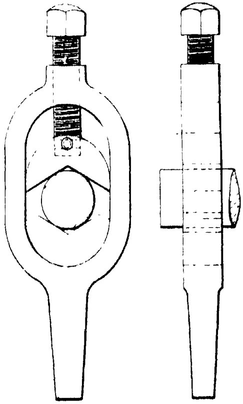


FIG. 153.—Adjustable screw carrier.

hold, which is due to a large extent to the local compression and distortion of the work-piece which oc-

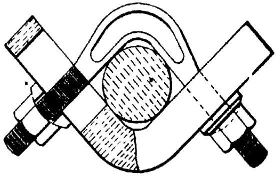


FIG. 154.—Clamp carrier.

cur at the places of contact between the work-piece and the carrier. Generally for driving small and

medium-sized work-pieces the screw carrier is employed since it gives a sufficiently strong grip for all ordinary machining operations in the lathe. When a screw carrier has to be placed on the finished end of a work-piece, it is very desirable to place a thin piece of brass or copper between the end of the carrier screw and the surface of the work-piece in order to protect the latter

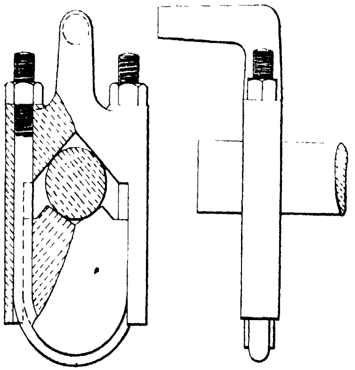


FIG. 155.—Clamp carrier.

The form of the centre-holes in the ends of a work-piece should be one compounded of a small parallel hole and a conical hole, as is indicated in Fig. 156, the small hole serving as a protector to the extreme end of the point of the centre and also as a small reservoir of oil for keeping the centre lubricated. The standard point-angle of lathe centres is 60° for small and medium-sized work-pieces, so

that the angle of the countersunk or conical part of the centre hole should also be 60° in order to obtain a satisfactory bearing of the centre in the hole. The form of centre hole indicated in Fig. 157 should never be used wherever it is possible to employ the other. The lubrication of the loose-headstock centre is always more important than that of the live centre in the driving headstock spindle.

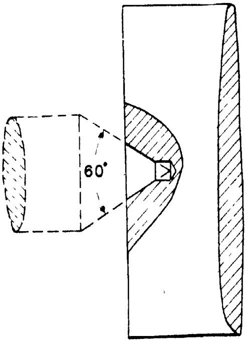


FIG. 156.—Point angle of lathe centre.

When very accurate results in the way of turning are required, it is necessary to see that the end of the work-piece is practically square with the axis. If it is not square, as shown in Fig. 158, then it is very desirable that it should be squared up by means of a side or knife tool before much work is done on the body of the work-piece, the condition indicated in Fig. 159 being the one which should obtain in every case where it is possible to realise it. This

is especially necessary if the work-piece is at all

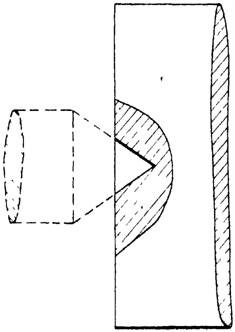


FIG. 157. Unsuitable form of centre hole.

slender, since, with a centre-bearing surface of varying breadth, the specific pressure exerted on the

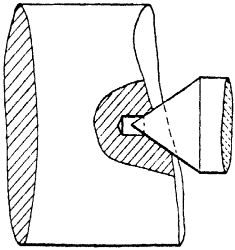


FIG. 158.—Fit of centre in centre hole of work-piece.

surface changes from instant to instant during the revolution of the work-piece. The result of this

that the angle of the countersunk or conical part of the centre hole should also be 60° in order to obtain a satisfactory bearing of the centre in the hole. The form of centre hole indicated in Fig. 157 should never be used wherever it is possible to employ the other The lubrication of the loose-headstock centre is always more important than that of the live centre in the driving headstock spindle.

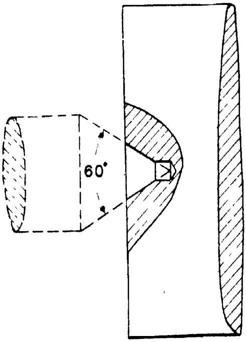


FIG. 156.– Point angle of lathe centre.

When very accurate results in the way of turning are required, it is necessary to see that the end of the work-piece is practically square with the axis. If it is not square, as shown in Fig. 158, then it is very desirable that it should be squared up by means of a side or knife tool before much work is done on the body of the work-piece, the condition indicated in Fig. 159 being the one which should obtain in every case where it is possible to realise it. This

the work-piece, and the line CD the new axis formed as the result of wear in the centre hole.

In squaring up the end of a work-piece, the end should not be left in the form represented in Fig. 161, the centre hole being preferably drilled deeper in the work-piece and the projection shown in the figure removed by means of a knife tool, unless there is some specific reason why such a projection

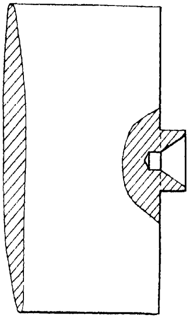


FIG. 161.—Undesirable form of end of work-piece.

should be left on, as there is in just one or two cases, but certainly not in many.

Machining Work-pieces on Mandrels.—Work-pieces which are centrally hollow, and have to be driven between the centres of a lathe, have to be mounted on mandrels, these latter being the parts which are arranged to rest directly on the centres.

The reasons for the use of mandrels are not quite the same in every case. The two chief reasons (which may operate separately or jointly in any

that the angle of the countersunk or conical part of the centre hole should also be 60° in order to obtain a satisfactory bearing of the centre in the hole. The form of centre hole indicated in Fig. 157 should never be used wherever it is possible to employ the other The lubrication of the loose-headstock centre is always more important than that of the live centre in the driving headstock spindle.

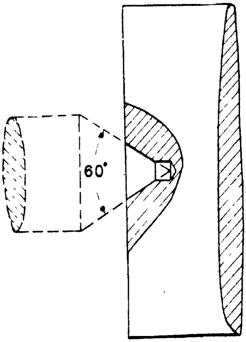


FIG. 156.– Point angle of lathe centre.

When very accurate results in the way of turning are required, it is necessary to see that the end of the work-piece is practically square with the axis. If it is not square, as shown in Fig. 158, then it is very desirable that it should be squared up by means of a side or knife tool before much work is done on the body of the work-piece, the condition indicated in Fig. 159 being the one which should obtain in every case where it is possible to realise it. This

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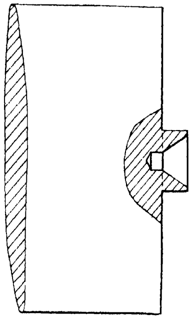

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Machining Work-pieces on Mandrels.—Work-pieces which are centrally hollow, and have to be driven between the centres of a lathe, have to be mounted on mandrels, these latter being the parts which are arranged to rest directly on the centres.

The reasons for the use of mandrels are not quite the same in every case. The two chief reasons (which may operate separately or jointly in any

should be a push or sliding fit in the work-pieces,

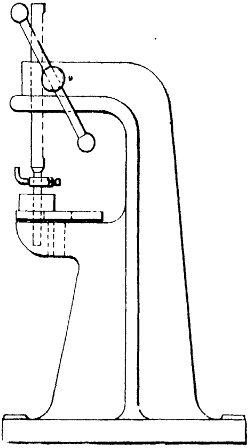


FIG. 163.—Mandrel Press.

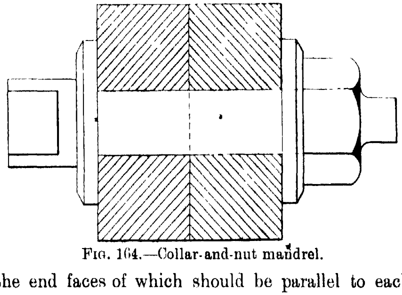


FIG. 164.—Collar-and-nut mandrel.

the end faces of which should be parallel to each other and normal to the axes of the holes.

Two forms of mandrel for carrying nuts which require to be faced in the lathe are indicated in Figs. 165 and 166. The former is a simple form for mounting between the centres. The latter is of a slightly more elaborate design, and, as shown, can

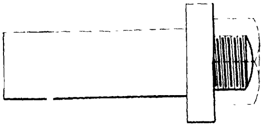


FIG. 165.—Nut mandrel.

be mounted directly on the nose of the driving spindle of a lathe. This latter design is such that the nut is allowed to accommodate itself on a washer with a curved seat, so that the nut, instead of having its back square with the axis of the

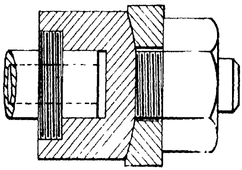


FIG. 166.—Adjustable nut mandrel.

mandrel, has its axis practically parallel to the mandrel axis, this latter condition being specially desirable in the case of rough or black nuts.

In connection with the driving of work-pieces on mandrels between the lathe centres, it is very desirable to see that the centre holes in the mandrels

are quite clean, as otherwise inaccurate work and over-heating at the tail-end of the mandrel might result.

Chucking Work-pieces.—A work-piece is held in a chuck by the radial pressures which are exerted on it by a number of jaws, these radial pressures producing a circumferential frictional resistance, which tends to oppose relative motion

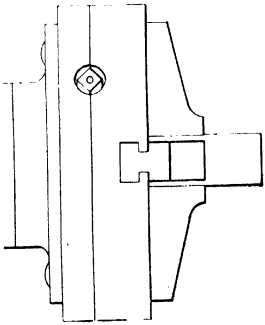


FIG. 167.—Use of four jaw chuck.

between the work-piece and the jaws. The methods of producing the radial pressures which are available are several in number, just as there are several forms of jaws.

In the ordinary lathe chuck there are either three or four jaws, and these are moved in radial directions either independently or collectively. In the former case, the chuck is of the independent-jaw type; in the latter it is of the self-centring or universal type. Independent-jaw chucks are generally

made with four jaws, whilst the majority of self-centring chucks have only three jaws.

When work-pieces are placed in self-centring chucks, they automatically place themselves central; when they are mounted in independent-jaw chucks, they have to be specially set central or ex-central, as the case may be.

The method of gripping a solid work-piece of

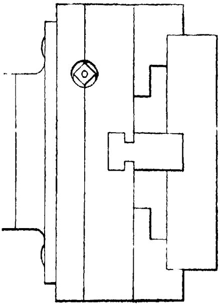


FIG. 168.—Chucking a large-diameter work-piece.

small diameter in a lathe chuck is indicated in Fig. 167. In Fig. 168 is shown the method of holding a solid work-piece of large diameter in a lathe chuck. In this case, the jaws used are stepped and not plain as those which are represented in Fig. 167, the work-piece being gripped by the outer short faces of the jaws.

When a hollow work-piece has to be gripped on the inside in a lathe chuck, stepped jaws have to be used, and these have to be set with their steps out-

side, contact being between one set of these and the inside surface of the work-piece. An example of inside chucking is shown in Fig. 169.

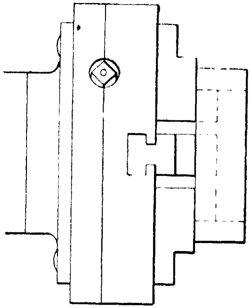


FIG. 169.—Chucking a hollow work-piece.

In Fig. 170 is indicated a method of ensuring true running in the case of a work-piece which has to

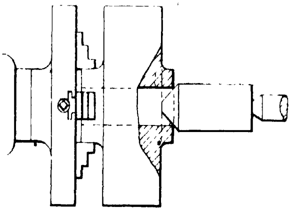


FIG. 170.—Method of chucking a heavy work-piece.

be chucked with a large amount of overhang from the ends of the chuck jaws. A pointed bar centred at the other end is employed as indicated, the

loose-headstock centre being used to keep the bar up against or in the work-piece. If the fit of the bar in the bore of the work-piece is a good one, then the bar will revolve with the work-piece and not be held by the frictional resistance in the centre-hole. If the work-piece is not hollow, then a small centre-hole may be drilled in it, and the centre of the loose-headstock used, or, failing this, a bar like the one represented in the figure, but with a sharp point (like a centre point) to fit in the centre-hole in the

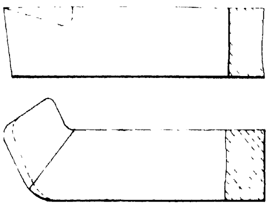


FIG. 171.—Solid lathe tool.

work-piece may be used between the work-piece and the loose-headstock centre.

Lathe Tools and their Setting.—Ordinary lathe tools may be divided into two classes, namely, the solid tool and the inserted tool. In Fig. 171 is represented one of the former class, whilst several examples of the latter class are shown in Figs. 172 to 175. The chief virtue of the inserted type of lathe tool is to be found in the economy in the use of tool steel which results from their employment. For the heaviest classes of turning, however, they do not appear to be suitable, owing to the heavy cutting forces which operate in these cases,

The shapes of the noses (cutting ends) of lathe tools depend chiefly upon the duties which the tools are required to perform and the nature of their work. Tools with long cutting edges *always* tend to set up chattering and vibration, which, trans-

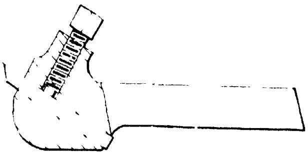


FIG. 172.—Inserted lathe tool.

mitted to the driving mechanisms of lathes, sooner or later have a deleterious effect on them. This tendency to set up vibrations is more pronounced in the cutting of the brasses and bronzes and alloy steels, which are high in nickel and chromium, than in the cutting of cast iron and plain-carbon steel.

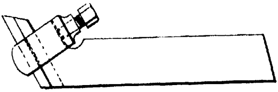


FIG. 173.—Inserted lathe tool.

On the other hand, a long cutting edge, other things being equal, connotes a high comparative durability of the edge, so that, in ordinary practice, it is usually found to be the best plan to adopt the mean, and so secure an average durability with a comparatively small amount of vibration.

In connection with some of the finer cutting

operations, this question of the setting-up of vibration as the result of cutting is a very important one, since in these operations finish of surface is usually required with exactitude of dimensions, neither of

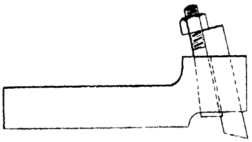


FIG. 174.—Inserted lathe tool.

these results being possible where there is a considerable tendency to set up vibration.

The angles of rake and clearance in relation to lathe tools are defined in practically the same way as are the same angles in relation to planer and

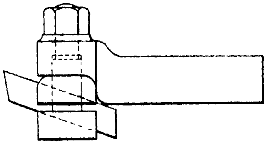


FIG. 175.—Inserted lathe tool.

shaper tools; the chief difference being that the clearance angle is, in this case, referred to the tangent to the circle of the work-piece at the point of cutting, whereas in the other cases it is referred to the surface of the work-piece itself.

In the case of the majority of lathe tools, the principal angles have the following limiting values:—

Metal to be Machined	Front Rake	Side Rake.	Clearance	Tool Angles.
Cast steel .	5° to 10°	10° to 15°	4° to 10°	75° to 81°
Alloy ,, .	5° ,, 15°	10° ,, 20°	3° ,, 8°	70° ,, 82°
Mild ,, .	10° ,, 20°	15° ,, 25°	4° ,, 10°	60° ,, 76°
Cast iron .	5° ,, 12°	10° ,, 20°	5° ,, 8°	68° ,, 80°
Bronze .	0° ,, 5°	0° ,, 5°	5° ,, 8°	77° ,, 85°
Brass	0° ,, 5°	0° ,, 5°	5° ,, 8°	77° ,, 85°

The setting of a lathe tool in the slide-rest tool holder needs careful consideration, since by incorrect setting it is possible to alter the operative angles of rake and clearance, a result that can also be achieved by altering the setting of the tool.

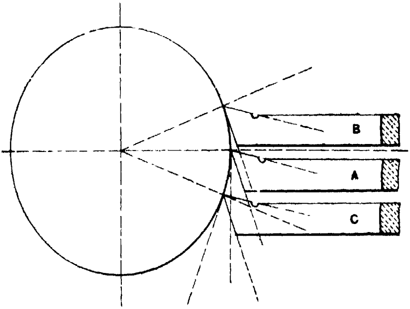


FIG. 176.—Lathe-tool positions.

The theoretically correct position of a lathe tool is such that the cutting point of the tool lies in the horizontal plane which contains the axis of the work-piece, and that the body of the tool is horizontal. This position is indicated at A in Figs. 176 and 177, and the effects of altering this position

in the eight ways which are possible are represented in Figs. 176 to 179.

In the cases represented in Fig 176, the tool is raised or lowered bodily in a direction at right angles to the length of the tool, so as to occupy either position B or position C. The effect of raising the tool in this manner is to increase the rake and reduce the clearance of the nose of the tool, whilst the effect of lowering the tool as shown

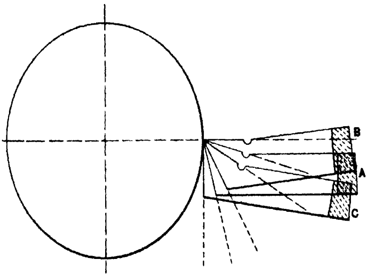


FIG. 177.—Lathe-tool positions.

at C is just the opposite of this, that is, the rake is reduced and the clearance is increased.

In Fig. 177 the effects of tilting the tool bodily about its cutting point are indicated. When the tool is raised into position B, the rake angle is reduced, and the clearance angle is increased by an equal amount, namely, the angle of tilt; whilst when the position of the tool is changed from A to C, the opposite effects are produced.

The effect in each of the cases represented in

Figs. 178 and 179 is of a compound nature, the compounding being that of the effect of normal

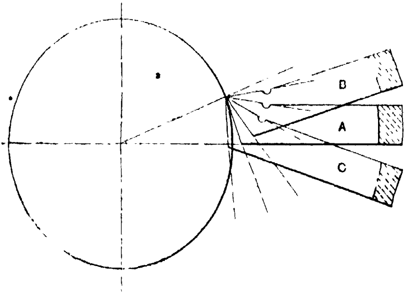


FIG. 178.—Lathe-tool positions.

movement and that of tilting of the tool. In the former figure are shown the effects of the super-

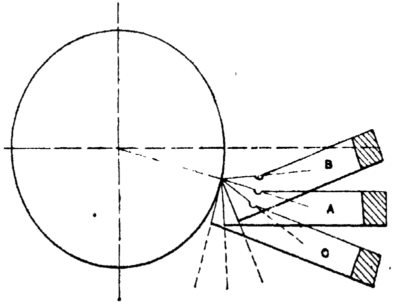


FIG. 179.—Lathe-tool positions.

position of a normal elevation of the tool and a tilting movement. When the tilting is upwards,

as shown at B, the effect is differential in character, the effect of the raising tending to neutralise that of the tilting, when the tilting is downwards, as at C, the effect is a cumulative one, it being the sum of the two individual ones. In Fig. 179 the opposite case is represented, the effects in this case being opposite to those which are associated with the positions indicated in Fig. 178.

It should be pointed out here that normal tool-adjustments are almost invariably made on lathes fitted with the English form of tool-clamp, and also on lathes fitted with certain designs of American tool-posts. Adjustment of the position of the cutting edge or point of the tool by tilting is, however, more commonly practised on American lathes than is the normal adjustment method.

Turning Cylindrical Work-pieces.—Work-pieces which are driven between the lathe centres cannot be turned truly cylindrical unless the cutting point or edge of the tool moves in a line parallel to the axis of the work-piece, which is, normally, coincident with the line joining the extreme ends of the points of the two centres. If the cutting point or edge of the tool does not travel along such a line, notwithstanding the fact that it may be always at the same normal distance from the vertical plane passing through the axis of the work-piece, the outline of the latter will not be that of a true cylinder. The conditions necessary for the obtainment of a truly cylindrical surface are represented in Fig. 180, the line AB representing the axis of the work-piece, and the line CD the path of the cutting point or edge of the tool. In the elevation the line CD may

be above or coincident with the line AB, but in the former case it must be parallel to it as in the figure. A set of conditions under which a truly cylindrical

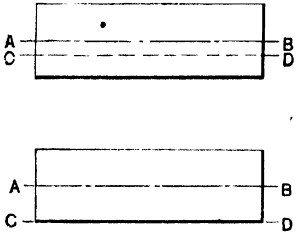


FIG 180. Cylinder-turning.

surface cannot be obtained is indicated in Fig 181. Here, it will be noticed, the path of the cutting point or edge of the tool is inclined to the axis AB

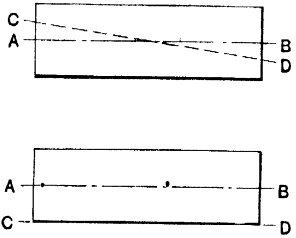


FIG. 181.—Cylinder-turning.

in the elevation. Under such circumstances satisfactory results cannot be secured.

Another point of importance in connection with the turning of a true cylinder has reference to the

maintenance of the straightness of the axis of the work-piece. If the latter is comparatively long and slender, unless it is supported at least at one point intermediate to its two ends, the forces due to cutting tend to set up vibrations and deflections and to cause the work-piece to spring and to ride over the cutting edge of the tool. The use of a travelling steady immediately behind the tool reduces this tendency to a minimum, and enables work-pieces of this kind to be machined satisfactorily in the lathe.

The question of the heating of the work-piece due to cutting, and its effect on the length of the work-piece, is also a matter of some importance when the work-piece is long and slender. The effect of the heating of the work-piece is, of course, to cause expansion in every direction, the greatest effect being in the direction of the length, owing to the disparity between the length and the diameter. Obviously, this elongation can only be reduced by keeping down the rise in temperature, which in turn can only be effected by either reducing the amount of heat generated or carrying away a large part of the heat as it is generated. The former method involves the reduction of the cutting speed or area of cut, or of both; whilst the latter involves the use of a cooling medium, such as soluble oil or soda-water. But even when due consideration has been given to these points, it is desirable that attention should be given to the loose-headstock centre, which should be eased back slightly in the event of the work-piece revealing a tendency to buckle or bend.

Plain turning is usually done by means of some form of round-nosed tool, the motion of the tool

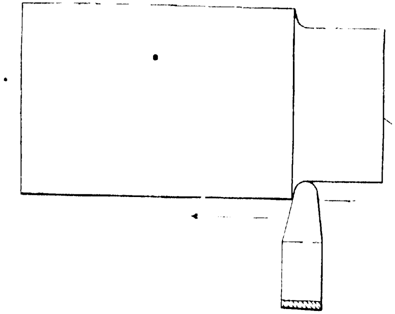


FIG. 182. Position of turning tool.

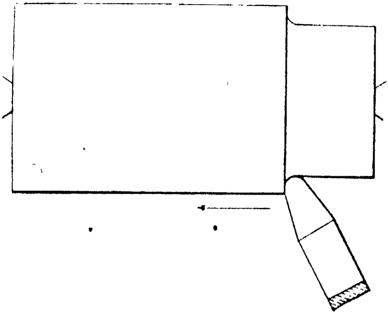


FIG. 183.—Another position of turning tool.

being obtained through the medium of either the slide-rest as a whole or simply the top-slide. In

the former case, the slide-rest is invariably power-actuated if the tool has more than a very short distance to travel; in the latter case, the slide is always hand-actuated.

In Fig. 182 is indicated the usual disposition of a straight round-nosed turning tool set for plain turning, in Fig 183 is indicated the disposition of the tool as adopted in certain cases. whilst in

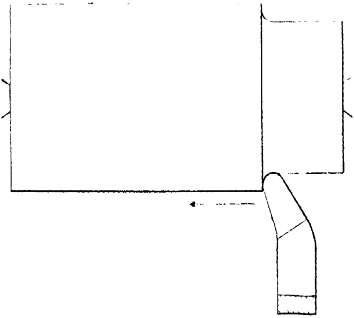


FIG. 184.—Right-hand side turning tool.

Fig. 184 is illustrated the use of a right-hand round-nosed tool under similar circumstances.

Surfacing.—By "surfacing" is meant a machining operation in connection with which the cutting tool has a motion in a direction at right angles to the axis of the work-piece, so that surfacing always has as its object the production of a flat or quasi-flat surface on a work-piece at right angles to its axis. In the engine lathe, this operation is always performed through the medium of the cross-slide,

this being hand or power-actuated according to circumstances.

In Fig. 185 is represented a right-hand side tool with a round nose as set and used for the surfacing of the side or end of a work-piece. If a straight

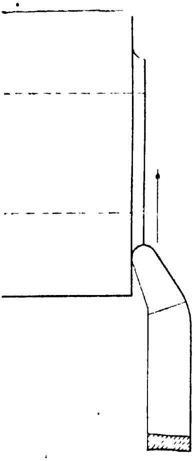


FIG. 185.—Surfacing tool.

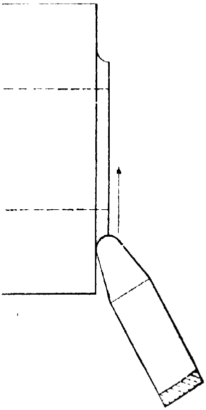


FIG. 186.—Surfacing tool.

tool is employed for the same purpose, it has to be set at an angle to the surface to be machined, as is indicated in Fig. 186. The use of a knife tool in a surfacing operation is illustrated in Fig. 187. In this case, the cutting edge of the tool is shortened somewhat by grinding, the object of this being the facilitation of the re-grinding of the nose

of the tool when the cutting edge requires re-sharpening. In this operation the tool should preferably be moved outwards, as indicated by the arrow, and the tool should be set so that the cutting edge has a *very slight* inclination outwards in the direction of motion of the tool. Further, if the

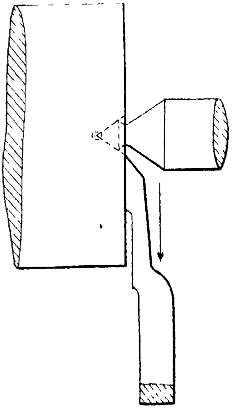


FIG. 187.—Facing with knife tool.

form of lathe centre shown in the figure is used, the whole surface of the end of the work-piece can be reached by the cutting edge of the tool, that is, from the edge of the centre-hole to the circumference of the end of the work-piece, without any appreciable difficulty.

Taper-turning.—Tapers are of two kinds, namely, single and double tapers. The former, which is

this being hand or power-actuated according to circumstances.

In Fig. 185 is represented a right-hand side tool with a round nose as set and used for the surfacing of the side or end of a work-piece. If a straight

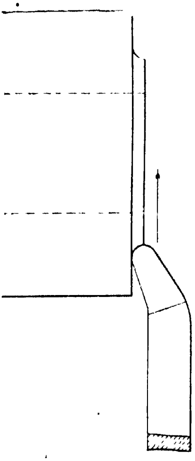


FIG. 185.—Surfacing tool.

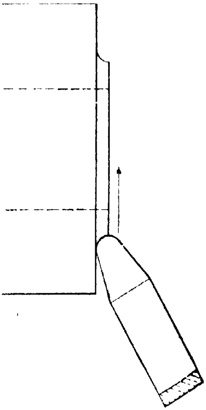


FIG. 186.—Surfacing tool.

tool is employed for the same purpose, it has to be set at an angle to the surface to be machined, as is indicated in Fig. 186. The use of a knife tool in a surfacing operation is illustrated in Fig. 187. In this case, the cutting edge of the tool is shortened somewhat by grinding, the object of this being the facilitation of the re-grinding of the nose

foot length of taper, X being the quantity indicated in the figure when the length of the base of the taper is 1 foot. The third method is to represent it by a fraction, with, preferably, 1 in the numerator, such as $\frac{1}{N}$ (see figure), in which N represents the length of the base, in inches, corresponding to a height or breadth of the taper of 1 inch. In the fourth

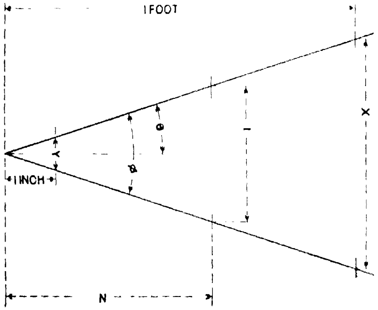


FIG. 189. Double-taper diagram.

method, the taper is stated as Y inch per inch length of taper, Y generally being a definite fraction of an inch. The following relations subsist between these several definitions:—

$$Y = \frac{1}{N} = \frac{X}{12} = \tan \theta \quad . \quad . \quad (20)$$

A double taper may be defined, for dimensional purposes, in five different ways corresponding to the above. The first is in terms of the total or included angle ϕ (Fig. 189); the second in terms

of a side angle θ, this angle being referred to the axis of the cone. The third method is to state it as X inches per foot length of taper, X being the quantity indicated in the figure, or the difference between the end diameters per foot length of taper. The fourth method is to represent it by a fraction, such as $\frac{1}{N}$, where N is the length of the taper in inches corresponding to a diametral difference of 1 inch. In the fifth method, the taper is stated in terms of the diametral difference per inch length of taper, that is, as Y inch per inch length of taper. The following relations subsist between these several definitions :—

$$Y = \frac{1}{N} = \frac{X}{12} = \tan\frac{\phi}{2} = \tan\theta \qquad . \quad (21)$$

A list of tapers giving the taper, the taper per foot length, the total or included angle, and the angle with the centre line, will be found in Table VII. of the Appendix.

In regard to the actual process of turning tapered work-pieces, there are at least five different ways of carrying it out in the engine lathe. These are —

(*a*) By means of the top-slide of the plain hand-rest or the more complicated slide-rest. In each case the top-slide is set over at the required angle with respect to the axis of the work-piece, this angle being the angle θ of Fig. 189, that is, one-half of the total or included angle of the taper.

(*b*) By setting over the loose-headstock centre, so that with a straight line travel of the cutting point of the turning tool parallel to the axis of the lathe, the distance between the axis of the work-piece and

the cutting point of the tool changes with the position of the latter. This condition is indicated in Fig. 190, which represents a plan view. The amount of set-over which is given to the loose-headstock centre is generally taken as one-half of the difference between the two end diameters of the required taper. The actual amount of set-over is represented by the dimension S of the figure. Theoretically, this method of determining the amount of set-over is not correct for

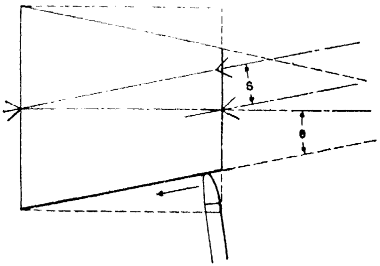


FIG. 190.—Taper-turning.

three important reasons: first, the length of the taper is greater than the line joining the extreme ends of the points of the lathe centres; second, the axis of the work-piece is not coincident in direction with the line joining the centre points on account of the fact that neither the driving-headstock centre (Fig. 191) nor the loose-headstock centre (Fig. 192) fits exactly in its centre hole in the work-piece: third, the end planes of the work-piece are not parallel to the direction of the set-over in the actual turning operation. Generally, however, where the

angle θ (Figs. 189 and 190) is small (that is, where the taper is a slender one), or where great accuracy is not essential, the above mode of computation is quite permissible, since the effects of the conditions just specified are not cumulative but differential in character. Where greater accuracy than that which is ordinarily required is demanded, the semi-diametral difference should be multiplied by cos θ, to obtain the amount of set-over of the loose head-stock centre. That is—

$$S = \frac{D - d}{2} \times \cos\theta \qquad . \quad (22)$$

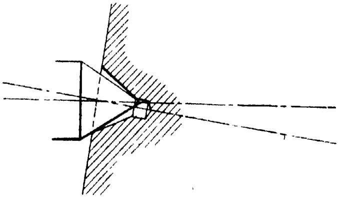


FIG. 191. Taper-turning.

where S is the required amount of set-over, D and d are the two end diameters of the work-piece, and θ is the side angle of the taper, that is, one-half of the total or included angle of the taper required. Values of cos θ for various tapers are given in Table VII. of the Appendix.

(*c*) By using a straight-edged cutting tool, and setting the edge of this at the required angle to the axis of the work-piece, that is, the angle θ. The position of the tool with respect to the work-piece is indicated in Fig. 193. A gauge for checking the

accuracy of the work when the work-piece is mounted on, and driven through the medium of a plain

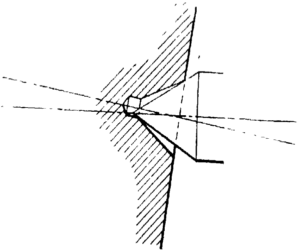


FIG. 192.—Taper turning.

standard mandrel is shown in Fig. 194 The manner of its use is obvious from the figure.

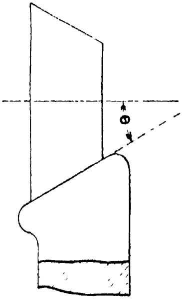


FIG. 193.—Taper-turning.

(*d*) By the employment of a taper-turning attachment, such as is found chiefly on American engine

lathes, for the control of the motion of the tool as the slide-rest travels along the bed This attachment consists of a bar, which can be fixed to the lathe bed in any position between the angles of + 5° and - 5° with respect to the axis of the lathe, and a block which is connected rigidly to the cross-slide of the slide-rest and arranged so that it can slide along the bar. Thus, as the saddle of the slide-rest moves along the bed of the lathe, the cutting point of the tool is constrained to move in a direction

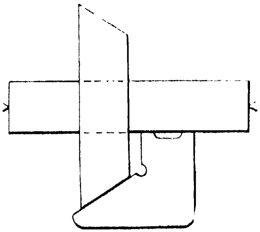


FIG. 194. Use of template in taper-turning.

parallel to the bar of the attachment. For many classes of work this is the most suitable method of turning tapers, though in many cases the graduations at *both* ends of the attachment are not quite correct. These graduations are usually given in *inches per foot* at one end of the bar and in *degrees* at the other.

(*e*) By combining the power cross-feed of the slide-rest with the power sliding feed. On some lathes these two movements cannot be obtained simultaneously; and in the cases of many others, the number of combinations is limited. There are, however,

some lathes which are so designed that it is possible to obtain an exceedingly large number of combinations of these two movements, the former being obtained directly from the lead-screw of the lathe, and the latter from the feed-rod or back-shaft through the ordinary gearing in the saddle-apron, the drive for this being obtained specially from the lead-screw and not directly from the driving spindle of the lathe. The principle of compounding is indicated in Fig. 195, in which figure the line AO represents the

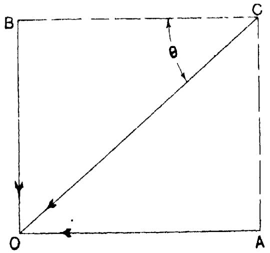


FIG. 195.—Diagram illustrating principle of taper-turning method.

saddle movement for a given number of revolutions of the work-piece, the line BO the cross-movement of the tool for the same number of revolutions of the work-piece, and the line CO the resultant of these two movements, that is, the actual movement of the cutting point of the tool in regard to both direction and magnitude. The angle θ represents the side angle of the taper that would be formed under such circumstances, and from the figure it will be seen that—

$$\tan\theta = \frac{BO}{AO} = \frac{\text{cross feed of tool}}{\text{longitudinal feed of slide-rest}} \quad (23)$$

by means of which relationship it is possible to determine the sizes of the wheels in the train of

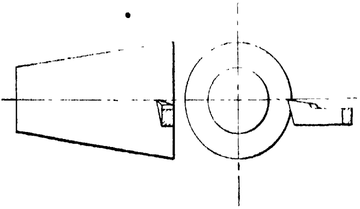


FIG. 196. Position of tool for taper-turning.

gearing which connects the back-shaft or feed-rod to the lead-screw.

An important point in connection with the correct formation of tapers is the position of the cutting

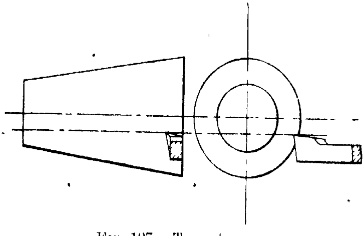


FIG. 197.—Taper-turning.

point of the tool with respect to the horizontal plane which contains the axis of the work-piece. Accuracy is possible only when the cutting point of the tool lies in this horizontal plane, as shown in Fig. 196,

whichever of the above five methods of obtaining the taper is adopted. If the cutting point of the tool is either above (Fig. 197) or below (Fig 198) this plane, the actual amount of taper formed will not be the same as that for which the machine was set

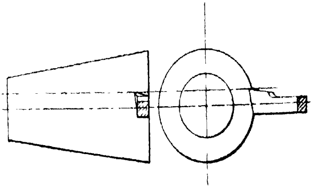


FIG. 198.- Taper-turning.

up, and the sides of the taper will not be straight lines but curves, the amount of curvature in any case depending upon the amount of taper required and the vertical distance between the cutting point of the tool and the axial horizontal plane, there be-

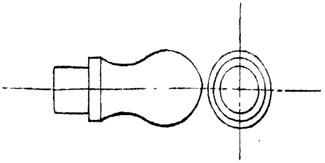


FIG. 199.- Formed work-piece.

ing no difference between a position above and one below this plane from this point of view.

Forming.—By forming is meant a machining operation in which a work-piece of a special shape or form is produced. The form or shape required

may be one which is referred to a plane passing through the axis of the work-piece, as in the case indicated in Fig. 199, or one which is referred to

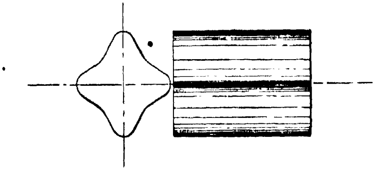


FIG. 200.—Formed work-piece.

a plane disposed at right angles to this axis, as represented in Fig. 200.

The first type of form can be machined in the lathe by means of a formed tool, the shape of which

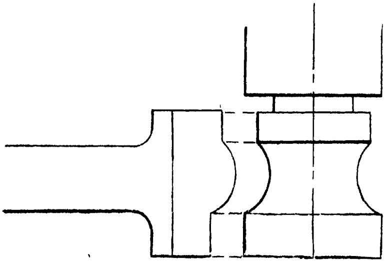


FIG. 201.—Use of formed turning tool.

is the negative of the shape required, as is indicated in Fig. 201, or by means of a former or copy bar which occupies a position with respect to the tool identical with that of the taper-turning attachment, the shape or form of the bar being practically the

same as the outline of the required form. Another method, where the form required is fairly simple in nature and no great accuracy is required, involves the simultaneous operation of the top-slide and cross-slide of the slide-rest by hand

The question of the position of the cutting point of the tool with respect to the axis of the work-piece which has been discussed in relation to the turning of tapers is of equal importance in this case.

Knurling.--The function of "knurling" or "milling" (as it is sometimes called) is the production of

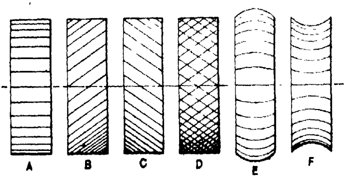


FIG. 202 - Forms of knurled surfaces.

a series of grooves and ridges on a curved surface of a work-piece in order to give a roughness to the surface which increases the power with which the work-piece can be gripped, either for the purpose of holding the piece in one position or for the purpose of turning it round.

The majority of knurled surfaces are either cylindrical surfaces, as shown in Fig 202, at A, B, C, and D, or convex or concave surfaces, as shown in the same figure at E and F respectively. In the case of knurled cylindrical surfaces, the grooves which form the knurling may be straight (Fig 202,

A) or helical (Fig. 202, B, C, and D), and in the latter case they may be either single left-hand (Fig. 202, B), single right-hand (Fig. 202, C), or double (Fig. 202, D). The grooves in convex and concave knurling are always straight, as shown in the figure.

Knurls are small wheels whose peripheries are provided with a series of sharp grooves and ridges which run all the way round and so form cutting edges of a kind, though then cutting action is necessarily very poor. The form of knurling shown at A in Fig. 202 is produced by means of a single cylindrical knurling wheel or knurl (as it is usually designated) with straight grooves, the forms shown at B and C by means of single cylindrical knurls with suitable helical grooves, that shown at D by means of two cylindrical knurls, with helical grooves and cutting edges of opposite hands, operating simultaneously; and those shown at E and F by means of a concave and a convex knurl respectively.

In Fig. 203 is indicated one method of setting up two knurls to be used together on the surface of a work-piece. The shank of the tool is held in the tool-post or holder of the slide-rest, and the knurls are pressed against the surface of the work-piece by the application of a force (indicated by the arrow in the upper view of the figure) through the medium of the cross-slide. The tool is made in two parts, with a hinged joint as shown, so as to allow the two knurls to accommodate themselves readily to the prevailing conditions and press equally against the work-piece. Two knurls are nearly always employed to produce the double form of knurling. When

only one knurl is used (as is the case with the formation of single knurling), it has to be held against the work-piece by pressure applied through the medium of a lever.

Cutting Speeds and Feeds.—The cutting speed in any particular case of lathe work depends upon a number of factors, chief of which are (1) the machining properties of the material to be machined; (2) the

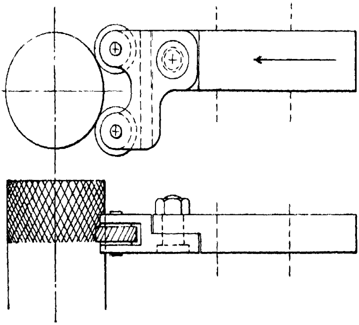


FIG. 203.—Knurling tool.

quality of the steel used in the tool; (3) the depth of cut; (4) the rate of feed; (5) the size and shape of the tool; (6) the length of time that should elapse between consecutive grindings of the tool; and (7) the use or non-use of a liquid as a cooling and lubricating medium.

Materials like cast tool-steel and the alloy steels have to be machined at much lower cutting speeds than have materials like mild steel and brass; and

in every case a much higher cutting speed is permissible if the cutting point of the tool can get below the skin or scale of the work-piece for the whole of its revolution than if it has to work on the scale during a part of the revolution—in fact, there is hardly anything else which has as pronounced a blunting effect on the cutting edge of a tool as having to work on the skin of a work-piece

Tools which are made of modern high-speed steel can be run at much higher cutting speeds than can tools made of ordinary plain-carbon steel, whilst tools made of superior high-speed steel can be run at higher cutting speeds than can tools made of ordinary high-speed steel.

The depth of cut and the rate of feed are determined to a very large extent by the general proportions and stiffness of the lathe, the kind of cut, the degree of finish required, and the strength of the piece of work being operated upon. Generally it is more economical, where much material has to be removed from the stock, to run at a comparatively low cutting speed with an increased depth of cut and rate of feed, with, if possible, preference being given to an increase in the depth of cut rather than to an increase in the rate of feed.

A tool which is so shaped that a long cutting edge is presented to the work-piece will, generally, admit of the use of a higher cutting speed than is permissible with a tool having a comparatively short cutting-edge under similar circumstances.

The use of a cooling and lubricating compound will usually result in the permissible increase of the cutting speed or of the area of cut, or conversely, it will

only one knurl is used (as is the case with the formation of single knurling), it has to be held against the work-piece by pressure applied through the medium of a lever.

Cutting Speeds and Feeds.—The cutting speed in any particular case of lathe work depends upon a number of factors, chief of which are (1) the machining properties of the material to be machined; (2) the

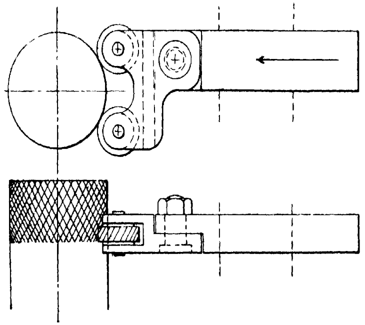


FIG. 203.—Knurling tool.

quality of the steel used in the tool; (3) the depth of cut; (4) the rate of feed; (5) the size and shape of the tool; (6) the length of time that should elapse between consecutive grindings of the tool; and (7) the use or non-use of a liquid as a cooling and lubricating medium.

Materials like cast tool-steel and the alloy steels have to be machined at much lower cutting speeds than have materials like mild steel and brass; and

values, which correspond to the above cutting speeds :—

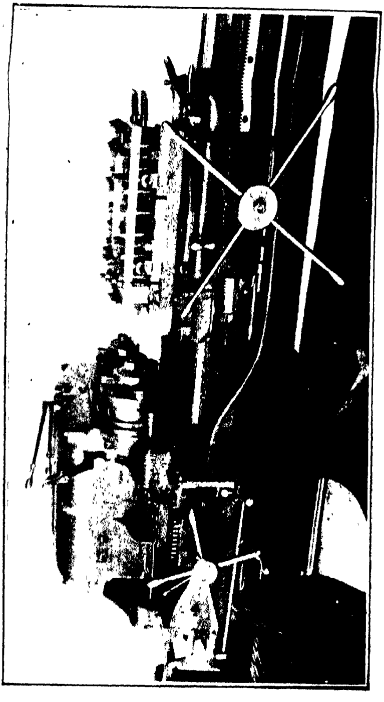
	Values of C.
On cast and alloy steels .	92 to 153
„ cast iron	114 „ 191
„ mild steel and wrought iron	137 „ 229
„ brass and bronze . .	191 „ 382

In Table VIII. of the Appendix are given the angular speeds corresponding to a series of cutting speeds and work-piece diameters.

2. Turret-lathe Methods. In turret and capstan lathes the work-pieces are generally gripped in, and driven by self-centring chucks (either split-collet or jaw chucks), and driven in this way without any outer support being given to them. Bars and rods which are of the drawn type, and therefore fairly uniform in cross-section with fairly smooth external surfaces, are held in collet or spring chucks almost invariably, unless they are of comparatively large diameter or section. Castings and forgings are universally held in jaw chucks or special chucks which act as jigs.

In Fig. 204 is illustrated a typical piece of work on a flat turret lathe equipped with two spindles so that two similar work-pieces can be machined identically and simultaneously. In this case, each work-piece (which is in the form of a casting) is gripped inside at the back by the three jaws of a self-centring jaw chuck, and each side of the turret is equipped with two similar sets of tools, so that, whatever the operation at any particular time happens to be, it is performed on both work-pieces in the lathe.

3. Automatic-lathe Work.—An example of this type of work is indicated in Fig. 205. This shows



how work-pieces, which have been roughed out in a turret lathe, are finished in an automatic turning

and facing lathe. In this form of lathe two tool holders are employed, one (shown at A in the figure) being for plain turning, and the other (shown at B) being for simple facing work. The turning tool-holder has an automatic motion in a direction parallel to the axis of the lathe, whilst the other has an automatic motion in a direction normal to this.

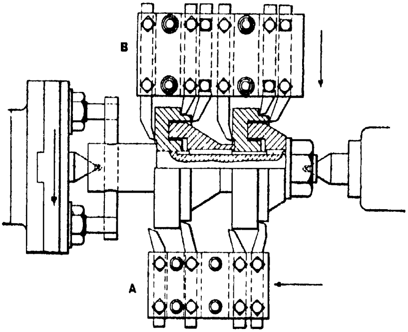


FIG. 205.—Machining work-pieces on automatic turning lathe.

In the case illustrated, two work-pieces, mounted on the same mandrel, are machined identically and simultaneously, ten tools (four turning tools and six facing tools) being required for this work.

Work of this type is purely repetition work and generally requires previous machining to have been done on the work-pieces before they can be operated on in this type of lathe.

CHAPTER VI

GRINDING AND LAPPING.

A CASUAL observation of a grinding operation often leads the uninitiated to the conclusion that there is nothing in the nature of cutting in grinding. This view, however, is quite wrong, and we know to-day that grinding is as much a machine-tool or tooling operation as is drilling or turning in the lathe, and that there are well-defined principles which underlie its satisfactory and efficient performance.

By grinding is meant the removal of stock by means of a wheel built up of abrasive or cutting material or materials and revolving at a very high speed. The abrasive material is in the form of crystalline grains, and these are held together in a bond or binding material in such a way that the outer surface of the wheel, whether plane or curved, contains a large number of sharp edges and points, these being chiefly of the grains of abrasive, though in some cases the binding material has an abrasive quality. It is in virtue of the presence of these sharp edges that a grinding wheel possesses what we call *cutting power*, and its cutting power depreciates as the outer edges of the abrasive particles grow blunt.

Abrasives.—The chief abrasives in common use are the natural sandstone or gritstone, emery, corundum, carborundum, alundum, and electrundum.

The ordinary sand grindstone, which is found in practically all general engineering workshops, is an abrasive wheel of, probably, the softest grade. It is a natural sandstone, and is sometimes associated with some form of lime.

Emery is a natural abrasive, and in its natural state it is found in many parts of the world, chiefly Greece, America, and Ceylon, the finest coming from the Island of Naxos. Emery is an impure form of corundum, which is an oxide of aluminium (usually known as alumina), the chief impurity being oxide of iron (magnetite), the proportions of the corundum and magnetite varying largely. The content of the alumina may be as high as 70 per cent. and as low as 30 per cent. The finest emery is that which contains the greatest percentage of alumina.

Corundum, which, as a natural substance, is not quite pure, its percentage purity ranging from 80 to 90 per cent., is mined chiefly in Canada. As an abrasive it is distinctly superior to emery for the majority of grinding operations, and, as a result of this superiority, is much more extensively used in modern grinding wheels than is emery, the decline of which dates from the discovery of extensive deposits of corundum ore in Canada. Gems such as the sapphire, turquoise, topaz, and ruby belong to the same class of natural substances as does corundum, the peculiar colours in such cases being due to the presence of certain metallic oxides in

the masses. Corundum has practically no colour, so that wheels made of corundum are coloured by the binding material only, such wheels consequently being distinguished by their light colour.

Carborundum is probably the hardest of all abrasives, both natural and artificial, after the several forms of the diamond. It is entirely an artificial product and is made in the electric furnace, the temperature of which is considerably over 2000° C. or 3600° F. Chemically, carborundum is a carbide of silicon, and it is formed by mixing in the furnace 50 per cent of carbon, in the form of coke and soot, 25 per cent of silica or aluminium silicate, in the form of sand, and 25 per cent of common salt, by weight, fusing, and then allowing the mass thus formed to cool. On the breaking-up of this mass it is found to consist of crystals, which are further broken up and graded according to their sizes. Carborundum is exceedingly brittle, chiefly on account of its glassy nature: hence, notwithstanding its great hardness, it is found to be unsuitable for use on materials of high tensile strength, such as steel; it is, however, very effective on chilled iron, cast iron, bronze, copper, and aluminium.

Artificial corundum is produced from ores of aluminium, these being reduced in the electric furnace and forming an oxide of aluminium of the same chemical formula as natural corundum. The ore which is chiefly used is a pure form of clay which is known as Bauxite, so named because it was first mined for this purpose at a place called Baux in France, though it is now obtained in other parts of the world. Artificial corundum is known

under a number of trade names, such as Alundum, Aloxite, Boro-Carbone, and Electrundum, and in nearly every case it contains slight percentages of other substances, such as iron, which improve its abrasive qualities.

Abrasive Wheels. An abrasive wheel consists of a large number of abrasive particles, usually in the form of crystals, which are held in position in a matrix or mass of binding material, the force which holds them in it being simply the tenacity of the binding material. So that, should any particle of abrasive be subjected to an external force which is greater than the tenacity of the bond round the particle, the particle is torn out of the wheel. As a matter of fact, this action is continually happening during the use of a grinding wheel, the rate at which it occurs varying in different cases.

Grit or Grain Size.—The size of the grains of abrasive which form the wheel determines what is known as the *grit* of the wheel. The grit or grain size of a grinding wheel is represented by a number, such as 46 or 60, this being the number of meshes per lineal inch of a sieve through which the particles have been passed after having failed to pass through the preceding finer mesh. Thus, 46 corundum particles are particles of corundum which have passed through a sieve having 46 mesh wires or threads per lineal inch of mesh. This number determines the coarseness or fineness of the wheel, a high number denoting fineness and a low number coarseness, so that a 20 abrasive is coarser than a 90 abrasive. Grits as coarse as 6 and as fine as 250 are made, though the majority of the grits which are

ordinarily employed lie between the relatively coarse grit of 16 and the relatively fine grit of 100.

Some grinding wheels are made of a mixture of particles of two grits, such as 38 and 60. These are known as *combination wheels*, the grain sizes being indicated by the compound of the two numbers —that is, 3860 in the case chosen

Bond.—The hardness of a grinding wheel depends entirely upon the bond or cement in which the abrasive particles are embedded and held, and is not related to any quality of the abrasive particles. This quality of hardness is determined by—

1. The nature of the binding material.
2. The treatment which the binding material undergoes during the process of manufacture of the wheel.

Abrasive wheels can be divided into four distinct classes according to the nature and treatment of the bond. These are:—

(*a*) Composition or elastic wheels.
(*b*) Silicate wheels.
(*c*) Vitrified wheels.
(*d*) Vulcanite wheels.

The bond of an elastic or composition wheel is either shellac, hard rubber, glue, or litharge (an oxide of lead) and linseed oil, which is mixed intimately with the abrasive particles and then allowed to dry, either naturally or at a comparatively low temperature.

A silicate wheel has silicates of soda and other bases as its binding material. The intimate mixture of the abrasive particles and the bond after the shaping operation, in which a mould is used, is subjected to a low temperature heating.

Vitrified wheels have certain clays, such as felspar or kaolin (china clay), as their bonds, the common feature of these clays being their high tensile strength. The mixtures of the abrasive particles and the bonds are made with fluxes which are very carefully chosen, and after the mixtures have been moulded to shape, they are initially dried, and then subsequently burnt or calcined in specially designed furnaces, or kilns, the temperature in this process reaching 3000° F

The bond of a vulcanite wheel consists of a mixture of india-rubber and sulphur. In this case the abrasive particles are mixed with the rubber and sulphur, moulded to shape, subjected to a very high pressure, and subsequently vulcanised by heat.

The bond of a vitrified wheel itself possesses abrasive properties which considerably enhance the cutting efficiency of the wheel. Further, in the process of vitrification the bond contracts, and as a result small inter-spaces are formed between the abrasive particles. Each particle thus stands out, and the metal removed in the grinding operation has a free passage from the stock, and does not therefore crowd itself into the wheel and thus impair the cutting efficiency of the latter.

Grade.—The hardness of an abrasive wheel is the tenacity with which the bond or cement holds the abrasive particles. It depends upon the relative amount of bond to abrasive in the wheel, as well as upon the nature of the bond, and is referred to as the *grade* of the wheel.

In the case of elastic and vulcanite wheels, the grade is represented by a number, the numbers in ordinary use ranging from 1 to 6, 1 representing the

softest grade and 6 the hardest grade in which these wheels are made.

In the case of silicate and vitrified wheels, the hardness-grading is done by means of the letters of our own alphabet, starting at A (extremely soft) and finishing at Z (extremely hard). For ordinary purposes the grades from J to P are chiefly used.

A complete list of grades with their corresponding degrees of hardness is given in Table IX. of the Appendix.

Glazing. Since the cutting ability of a grinding wheel depends upon the number and the sharpness of the cutting points or edges present in the active surface of the wheel, it is obvious that, if by any means the number or the sharpness of the cutting points or edges is reduced, the cutting ability of the wheel is likewise reduced. In the case of a satisfactory wheel, when the cutting point or edge of any abrasive particle has reached a certain degree of bluntness, the particle is detached from the wheel under the influence of the tangential cutting force, thus allowing the cutting point or edge of another particle to come into action. If this does not happen, the working surface of the wheel becomes covered with a large number of flat, smooth surfaces which are more or less polished in appearance and give a glazed appearance to the surface—hence the name *glazing*, by which this phenomenon is described. On the other hand, if the bond of the wheel is too soft for the work, the abrasive particles will be dissevered from the wheel too readily, and though the wheel will be a fast cutting one, it will also wear down excessively. Hence, it is necessary to select

a grade of wheel which will give neither glazing nor excessive wear.

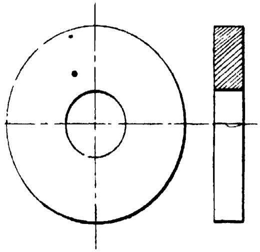


FIG. 206.—Disc wheel.

Abrasive Wheel Shapes.—The three chief shapes of abrasive wheels for external work are the disc wheel (Fig. 206), the dish or saucer wheel (Fig. 207),

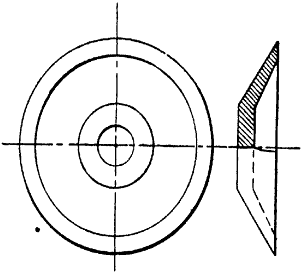


FIG. 207.—Saucer or dish wheel.

and the cup wheel (Fig. 208). For internal work the disc type of wheel (Figs. 209 and 210) is chiefly employed. A modified form of disc wheel is indicated in Fig. 211, whilst various forms of disc

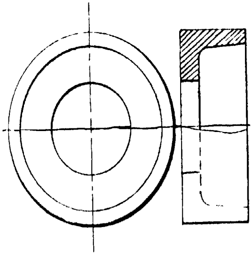


FIG. 208.—Cup wheel

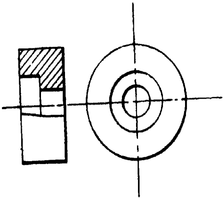


FIG. 209.—Internal wheel.

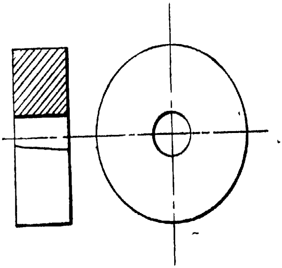


FIG. 210.—Internal wheel.

wheel edges are shown in Fig. 212. The cylinder or ring wheel (Fig. 213) and the tapered cup wheel

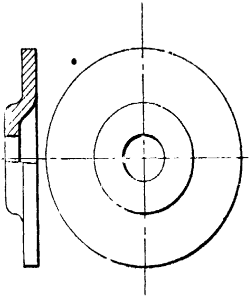


FIG. 211 Modified form of disc wheel.

(Fig. 214) are sometimes used in place of the ordinary cup wheel. In Fig. 215 a flanged form of wheel is indicated, it being possible to use both sides of this.

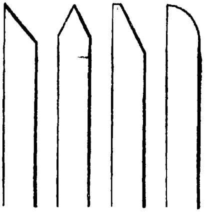


FIG. 212.—Edge profiles of disc wheels.

The disc type of wheel is used for both surface and circular grinding, as well as for tool and cutter grinding; the dish or saucer type is used chiefly for

circular grinding; whilst the cup type is used chiefly

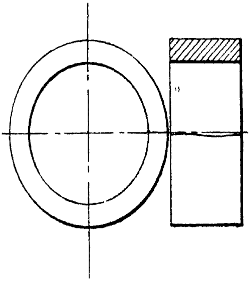


FIG. 213. Cylinder wheel.

for the production of flat surfaces, such as the faces of lathe and planer cutting tools.

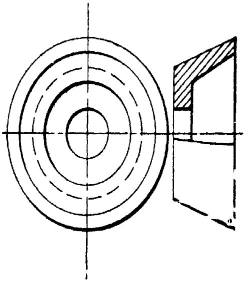


FIG. 214.—Tapered cup wheel.

Abrasive Wheel Mounting.—The mounting of an abrasive wheel on its spindle requires a considerable amount of care. In the first place the wheel

should not be crowded on the spindle, that is, the wheel should be a fairly easy sliding or push fit on the spindle, the diameter of the latter being about 0·005 inch less than the diameter of the hole in the wheel. This applies in the case of wheels with lead centres as well as in that of plain wheels.

A further point has reference to the fit of the collar and washer which are employed to hold the wheel on the spindle. The contact between these and the

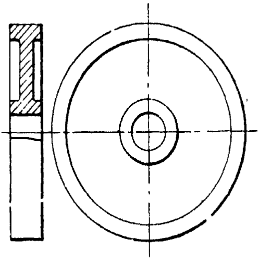


FIG. 215. Flanged wheel.

surface of the wheel should be towards the outer edges of the collar and washer (as shown in Fig. 216). Between the collar and the washer and the wheel, washers made of blotting-paper or other compressible material should always be inserted. They serve to distribute the pressure evenly over the surfaces of the wheel. The collar should preferably be secured to the spindle to prevent its rotation with the wheel relatively to the spindle. The hand of the screw-thread on the spindle should be such that the resistance to the motion of the wheel exerted by the work-piece tends to tighten the nut up against

the washer. That is, the thread should be right-hand if the direction of rotation of the wheel is counter-clockwise, and left-hand if the direction is clockwise, when observation is made on the nut side of the wheel.

Wheel Speeds.—The circumferential speed of abrasive wheels which is found to give the most satis-

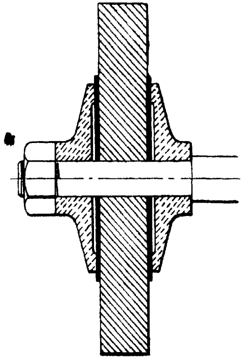


FIG. 216.—Method of mounting a disc wheel.

factory results varies from 4500 to 6000 feet per minute, though many of the larger wheels are run at speeds which are considerably below these. Every abrasive wheel after manufacture is tested at a circumferential speed of about 9000 feet per minute, this speed corresponding to a rim stress in the wheel of about 75 lbs. per square inch. In actual working, the rim stress should never exceed 25 lbs. per square inch, this being a safe working stress for all the binding materials used in abrasive wheels.

Work Speeds.—A considerable difference of opinion exists as to the most suitable surface speed at which to run the work-piece. Surface speeds as high as 150 feet per minute have been used, but the tendency at the present time is to use much lower work speeds, from, say, 25 to 50 feet per minute.

Finishing work speeds are usually about 25 per cent below the corresponding roughing speeds.

Relation between Wheel and Work Motions.—In regard to the relation between the directions of rotation of the wheel and the work-piece in circular or cylindrical grinding, the condition to be satisfied is that, at the point of contact, the two directions are opposite. This is indicated in Fig. 217 for both external and internal grinding. It will be noticed that this is precisely the same condition as that which should hold in milling operations (Fig. 116).

Truing-up Abrasive Wheels.—Abrasive wheels are trued up and dressed by means of special rotating discs or cutters, or by means of specially mounted diamonds. For the lighter wheels, and where accurate shapes are required, the latter method alone is suitable.

Disc Grinding.—The disc abrasive wheels already referred to should not be confused with the wheels of so-called disc grinders. These wheels are steel discs which rotate generally at speeds which are at least twice as great as those at which ordinary abrasive wheels of the same diameters run, and on their front faces are cemented or glued specially prepared abrasive (emery or corundum) paper or cloth, preferably the latter. The abrasive particles on the paper or cloth act in exactly the same way

as the abrasive particles in a grinding wheel do, though, naturally, in this case no truing or re-sharpening is possible as in the case of the wheel. Disc grinding is essentially surface grinding, its chief

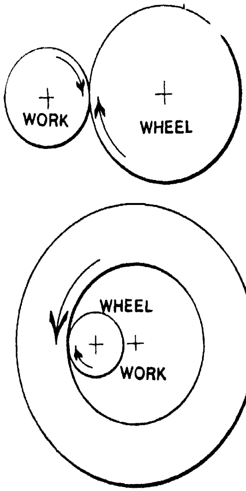


FIG. 217.—Diagrams showing directions of revolutions of grinding wheel and work.

features being the high speed which is permissible (2000 r.p.m. in the case of a 20-inch disc) and the low cost of renewal of the abrasive element.

Lapping.—This is a form of cutting which belongs to the grinding class. It is, however, distinct from grinding inasmuch as the cutting element is a wood

or metal body whose surface, as far as possible, is impregnated or charged with abrasive particles. The body, which is known as the *lap*, may be made of cast iron, mild steel, brass, copper, lead, or wood, and the abrasive may be diamond powder, corundum, ground glass, emery, carborundum, rouge, crocus powder, or tripoli powder. The abrasive powder is well mixed with oil or turpentine to form a paste for application to the working surface of the lap, the coarser powders being used in the heavier lapping operations. Rouge and turpentine is a good compound for finish lapping. In no case, however, is the grade of the abrasive very coarse.

Lapping is chiefly applied to external and internal cylindrical surfaces, flat end surfaces, and the surfaces of screw threads. Its purpose is twofold: (1) to produce a higher degree of finish than can be obtained by grinding or any other method except polishing; (2) to correct errors on ground, hardened work-pieces, or to give greater geometrical accuracy to these. A lap should, therefore, be at least quite as accurate as the surface to be lapped is required to be and, if possible, it should be even more accurate. This condition, generally, is not very difficult to realise, since laps are made of unhardened metals which are readily amenable to the action of ordinary cutting tools.

In regard to the use of laps, it may be pointed out that it is not desirable that there should be an excess of abrasive material on the lap, since, with this condition of excess satisfied, the abrasive has no real lodgment in the lap and has therefore a pronounced tendency to roll round between the lap and the

work-piece and so cut into both. For rough lapping the most suitable combination is an open-grained cast-iron lap and coarse diamond or carborundum powder. For finish lapping, a brass lap and rouge,

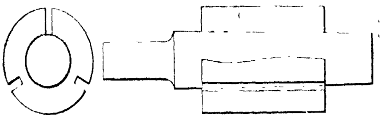


FIG. 218.—Internal lap.

diamantine, or crocus powder is a combination which yields good results. Carborundum paste has been found to give good results as a lap abrasive; it does not require to be mixed with oil for charging.

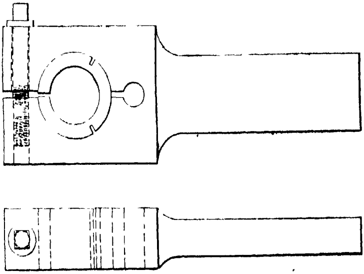


FIG. 219.—External lap.

Laps for internal and external cylindrical lapping should be of the adjustable types (Figs. 218 and 219), so that the pressure between the work-piece and the lap can be varied at will to suit the conditions prevailing at any particular place on the surface being lapped.

For the lapping of end surfaces which have to be flat, as the ends of certain measuring screws, it is necessary to use laps with plane working surfaces. To ensure that the end surfaces will be normal to the axis of the work-pieces a lapping holder of the form indicated in Fig. 220, or of a similar form,

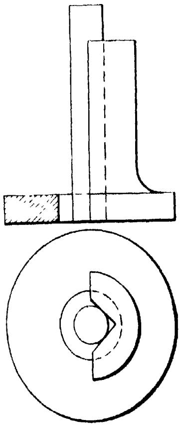


FIG. 220. -Holder for lapping flat ends.

should be used. The use of this holder is simple, the work-piece being held up in the vertical vee-groove during the lapping operation, and occasionally slightly turned about its own axis. The lap in such a case is a cast-iron plate with a plane upper surface containing a number of shallow groves normal and parallel to each other, this being used as

the lapping surface, and as such charged with the abrasive compound.

Abrasive Slips and Stones.—The oil-stone has been used for many years for putting the finishing touches on the faces and edges of cutting tools. Abrasive slips and stones of various sections and lengths are now made of such abrasives as carborundum and alundum. These are extremely useful for the finishing of hardened parts by hand, and take the place of hand laps, which they resemble in action but not in construction.

CHAPTER VII.

SCREW-THREADS AND THEIR FORMATION.

A SCREW-THREAD is a projection or ridge of definite sectional form which runs round a cylinder or cone in the form of a helix, the helix being usually of such a character that the distance from any one point in any convolution or turn to a corresponding point in the next convolution or turn is a constant one. A screw consists of the combination of a cylinder or cone and a helical projection, the commonest screws being those which have threads formed on external or solid cylinders, or in internal or hollow cylinders. The latter are known as nuts in the majority of cases.

A screw may have either one or a number of thread helices formed on it. The first form is known as a single-threaded or single-start screw; the second as a multiple-threaded or multiple-start screw. Again, a multiple-threaded screw may have two, three, four, or any greater whole number of thread helices, the only difference between the helices being in regard to their positions on the screw.

Pitch and Lead.—In the case of a single-threaded screw, the distance from any one point in any convolution of the thread helix to the corresponding point in the next is called the *pitch*. In the case of multiple-threaded screws it is called the

ead, which is sometimes defined as the axial or ongitudinal movement of the screw in the nut per evolution of itself. In this latter case, the *pitch* of he screw-thread is equal to the *lead divided by the number of separate threads*, and it is the distance rom any one point in any convolution of any thread ielix to the corresponding point in the corresponding convolution of the next thread helix. The *pitch* and *lead* of a *single-threaded screw* are *identical*. This difference between pitch and lead is not suffi-

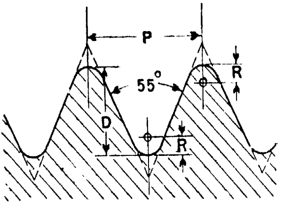


FIG. 221.—Sectional shape of Whitworth thread.

ciently recognised in this country, and much confusion occurs as the result of the failure to distinguish between them.

Forms of Thread Sections.—The sectional shape of the thread helix is definite for each of the standard threads in use. The section of the thread referred to in every case is one which is contained in a plane which passes through the axis of the screw, and not one which is normal to the thread helix.

The sectional form of the *Whitworth* standard thread is shown in Fig. 221. The two flanks of this thread are each inclined to the plane normal to the axis of the screw at an angle of 27½°, making the

total or included angle of the section 55°. The top or crest and the bottom or root are equally rounded, the radius R being equal to 0·1373 time the pitch

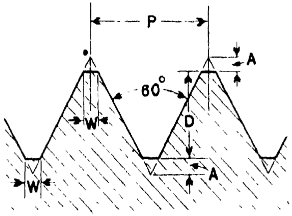


FIG. 222. Sellers vee thread.

(P). The depth (D) of the thread equals 0·64033 time the pitch.

The sectional form of the *Sellers* thread (Fig. 222) is that of a truncated equilateral triangle, the width

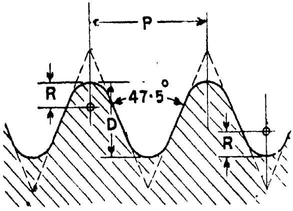


FIG. 223.—B.A., or British Association thread.

(W) of the flat at the top and the bottom of the thread being one-eighth of the pitch, and the depth (D) of the thread 0·6495 time the pitch.

The *British Association* standard thread (Fig. 223), known shortly as the B.A. thread, has a round

crest and root, the thread-section angle being $47\frac{1}{2}°$, the radius of curvature (R) of the crest and root

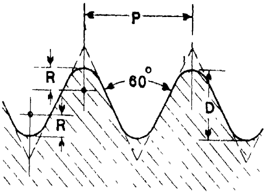


FIG. 224.—Cycle Engineers' Institute standard thread.

being two-elevenths of the pitch, and the depth 0·6 of the pitch.

The *Cycle Engineers' Institute* standard thread

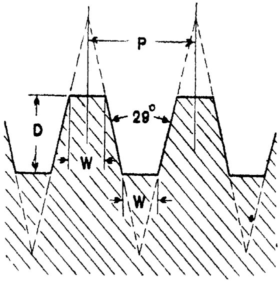


FIG. 225.—Acme thread.

(Fig. 224) is rounded, and of 60°. The crest and root radii are each equal to one-sixth of the pitch.

The *Acme* standard thread (Fig. 225) has an in-

cluded angle of 29°, the top and bottom of the thread being flat and of a width equal to 0·371 time the pitch.

The *Square* thread (Fig. 226) has a depth which is generally equal to one-half of the pitch or 0·025 time the pitch less than this.

Screw-thread Rake.—The rake of a screw-thread is the inclination of the thread to a plane normal to the axis of the screw. Now, it can be readily shown that this angle is, in any given case, greatest at the bottom of the thread, and least at the top, and that

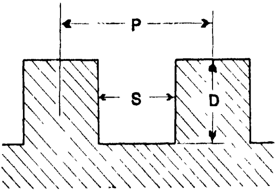


FIG. 226.—Square thread.

the relation between these values depends upon the outside diameter of the screw, the depth of the thread, and the pitch (or lead, as the case may be) of the screw. This is shown in Fig. 227, in which P represents the pitch, C_0 the outside or top circumference, C_1 the inside or bottom circumference, and θ_1 and θ_2 the two rake angles respectively.

For certain purposes, such as that of examination by optical projection, the angle of rake (θ, Fig. 227) is taken at what is variously known as the effective, pitch, or angle diameter, which is, in the case of a correctly formed screw, the mean of the outside and

bottom or core diameters. For the grinding of threading tools in some cases the angle of rake corresponding to the outside diameter is taken; in others, that corresponding to the core diameter.

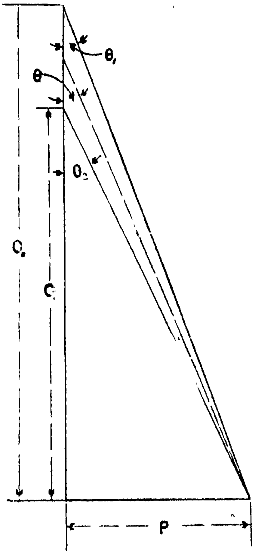


FIG. 227.—Diagram illustrating screw-thread rake.

Effective Diameter of a Screw.—In the case of any actual screw, the effective angle, or pitch diameter, is the distance, measured in a direction perpendicular to the axis of the screw, between the

part of the thread section whose width is equal to one-half of the pitch and the part of the thread groove immediately opposite which is also one-half of the pitch wide. The effective diameter of a screw gauge is an important element. Its working value is actually greater than its measured value if the pitch of the thread is not constant from convolution to convolution of the helix and also round each convolution. Its actual measurement is accomplished by means of thread micrometer calipers and also by means of ordinary micrometer calipers and needles, wires, or rods.

Hands of Screw-threads.—A screw-thread is a right-handed one if the screw has to be turned towards the right (that is, clockwise) in order to screw it in or on its mating element; it is left-handed if the direction of turning is counter-clockwise.

Methods of Cutting Screw-threads.—Both external and internal screw-threads are now formed in the various forms of the lathe by means of single pointed cutting tools, formed tools, chasers, dies, rollers, abrasive wheels, and thread milling cutters. The only other machine in which screw-threads are formed is the drilling machine converted into a tapping machine, and in this case they are usually only internal threads which are formed. External screw-threads are formed by hand by means of dies which are either solid or held in holders called stocks. The nut die has an external form which is either square or hexagonal, so that an ordinary spanner can be used on it. The nut die is used chiefly for removing bruises and burrs from screw threads already formed on pipes, bolts, and studs.

Internal screw-threads are formed by hand by means of taps. In a set of hand taps there are three taps (Fig. 228). The first of the three is called the taper tap, and is of such a form that the diameter of the starting end of the tap is not greater than the core or bottom diameter of the tap, that is, the so-called tapping size of the hole. The second tap is known by some engineers and mechanics as the second tap; by others it is known as the plug tap. The third tap is known as the plug or bottoming tap according as the second tap is known as above. Each tap is turned in the hole of the work-piece by means of a wrench, such as is illustrated in Fig. 52.

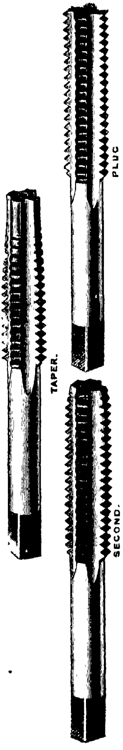


FIG. 228.—Set of hand taps.

Setting the Thread-cutting Tool in the Lathe.—In Fig. 229 are indicated two methods of using the ordinary thread-cutting gauge in connection with the setting of single-pointed thread-cutting tools in the lathe. Method A is the one which is the more commonly used, though Method B always provides a check upon the setting by method

A when the section angle of the thread is 60°. In Fig. 230 three methods of setting the corresponding internal tools are shown.

Cutting Right and Left-hand Screw-threads.—The chief difference between the set-up of a lathe for cutting a right-hand thread and that for cutting a left-hand thread is in regard to the direction of

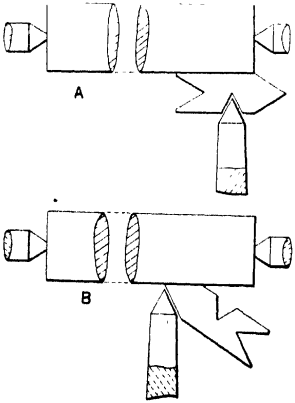


FIG. 229.—Methods of setting external thread-cutting tools.

rotation of the lead or guide screw which controls the motion of the slide-rest and tool. One method of changing this direction involves the use of the so-called reversing plate or cluster which is found on nearly every screw-cutting lathe—one would be justified in saying every screw-cutting lathe, since where the ordinary reversing-plate device is not a part of the design of the machine, its equivalent is,

In Figs. 231 to 233 are shown three positions of the reversing plate, P, of a screw-cutting lathe. The

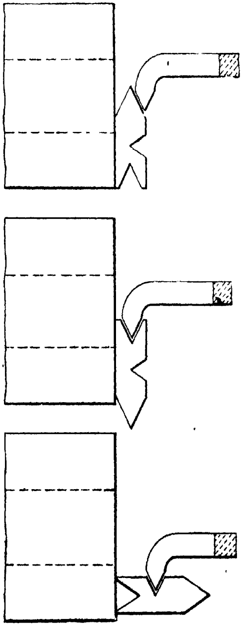


FIG. 230.—Methods of setting internal thread-cutting tools.

wheel A is the first in the train to the lead screw; it is mounted directly on the driving spindle of the headstock. The wheels B and C are of the same

A when the section angle of the thread is 60°. In Fig. 230 three methods of setting the corresponding internal tools are shown.

Cutting Right and Left-hand Screw-threads. —The chief difference between the set-up of a lathe for cutting a right-hand thread and that for cutting a left-hand thread is in regard to the direction of

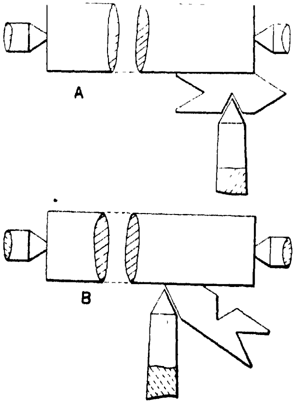


FIG. 229.—Methods of setting external thread-cutting tools.

rotation of the lead or guide screw which controls the motion of the slide-rest and tool. One method of changing this direction involves the use of the so-called reversing plate or cluster which is found on nearly every screw-cutting lathe—one would be justified in saying every screw-cutting lathe, since where the ordinary reversing-plate device is not a part of the design of the machine, its equivalent is,

wheel train; this, however, is not always practicable.

Change-gear-Wheel Computation.—The two ordinary arrangements of change-gear wheels without gear-box are indicated in Figs. 234 and 235. The former figure illustrates the case of simple

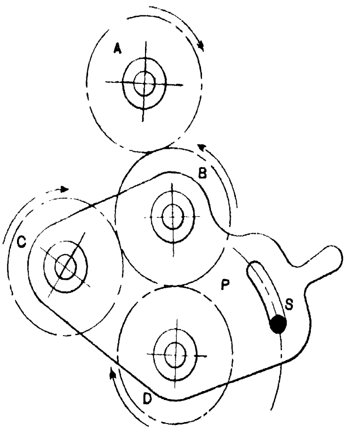


FIG. 232.—Forward position of reversing plate.

gearing, and the latter that of compound gearing. SW is the stud wheel, IW the intermediate wheels, and LW the lead-screw wheel.

The numbers of teeth in the change-gear wheels required in either of the above cases can be computed as follows: let P = the pitch of the lead-screw, and p = the pitch of the screw-thread to be

cut, assuming the screw to have a single-start thread, since otherwise we must take the lead of the screw-thread instead of the pitch. Then, we have that—

$$\frac{\text{Product of numbers of teeth in driving wheels}}{\text{Product of numbers of teeth in driven wheels}} = \frac{p}{P} \quad . \quad . \quad . \quad . \quad . \quad (27)$$

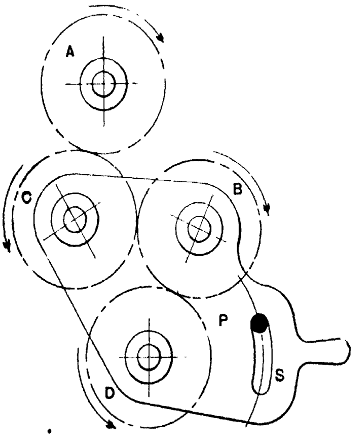


FIG. 233.—Reverse position of reversing plate.

The driving wheels are the wheels on the stud and the second wheel on the quadrant plate; the driven wheels are the first wheel on the quadrant plate and the wheel on the lead-screw.

The fundamental formula for the calculation of

the numbers of teeth in the change-gear wheels required in connection with the cutting of metric threads on lathes with English lead-screws is as follows:--

$$\frac{\text{Product of numbers of teeth in driving wheels}}{\text{Product of numbers of teeth in driven wheels}} = \frac{5}{127} \times \frac{m}{P} \quad . \quad . \quad . \quad . \quad (28)$$

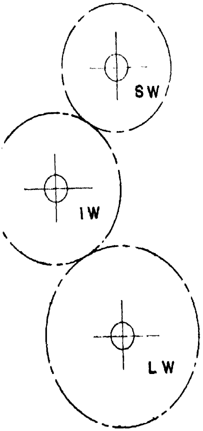


FIG. 234.—Single change-wheel gearing.

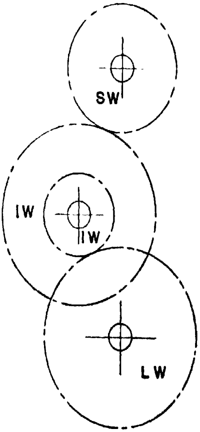


FIG. 235.—Compound change-wheel gearing.

where m = the pitch of the screw-thread to be cut, in millimetres. A wheel having 127 teeth is an essential part of the train of change-gear wheels in all cases in connection with which this formula is used,

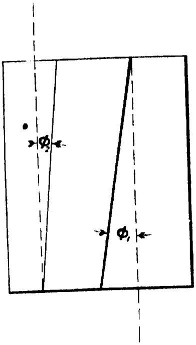


FIG. 236.—Square-thread cutting tool.

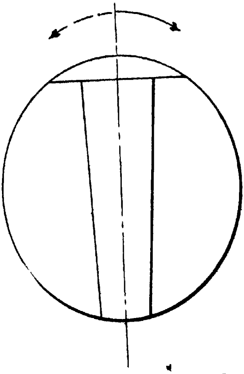


FIG. 237.—Another form of square-thread cutting tool.

Square-thread Cutting Tools.—The sectional shape of the nose of a threading tool for the cutting

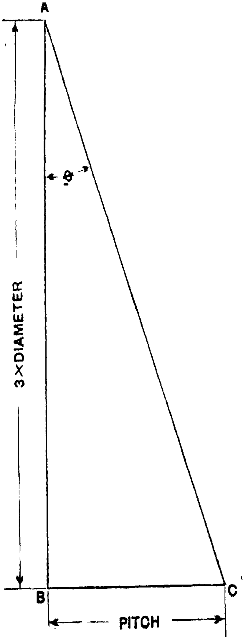


FIG. 238.—Diagram for setting square-thread cutting tool.

of square threads is indicated in Fig. 236. The angle ϕ_1, which is the inclination of the leading flank of the nose to the vertical, should be equal

to the angle θ_2 (Fig. 227) plus 2° or 3° of clearance. The angle ϕ_2 is the inclination of the following flank of the nose to the vertical, and should be made equal to the angle θ_1 of Fig. 227.

For the cutting of coarse-pitched screw-threads tools made of round-sectioned steel are generally preferred. In such cases the nose of the tool is ground to the shape indicated in Fig. 237, and the tool is turned through a small angle about its own axis. This angle is the same as the angle ϕ_1 of the preceding figure, and its magnitude is often found in the shop by drawing a right-angled triangle (Fig. 238), the base of which equals the pitch or lead (as the case may be), whilst the height equals three times the outside diameter of the screw. The direction in which the tool is turned about its own axis depends only upon the hand of the thread to be cut: if the thread is a right-hand one, the direction is that indicated by the full arrow of the figure, if it is a left-hand one, the direction is that indicated by the dotted arrow, observation being taken towards the nose of the tool in each case.

CHAPTER VIII.

INTERCHANGEABLE SYSTEM OF MANUFACTURE.

The fundamental principle of modern engineering manufacturing methods is that of interchangeability between similar parts or elements of the machines or constructions manufactured. Interchangeability is in essence an economic proposition, and upon the degree of success realised in its attainment the cost of manufacture undoubtedly depends. It is, however, very difficult to attain unless modern methods of machining are adopted.

The adoption of this system of manufacture necessitates that all similar work-pieces shall be machined to dimensions which lie between fixed limits, and that work-pieces which are machined to dimensions which lie outside these limits shall be rejected for correction where this is possible.

To explain the system we will take as an illustration the comparatively simple case of a journal shaft and bearing. To give satisfactory service the fit between the journal and the bearing must be of a certain kind: if it is too loose or free, excessive vibrations might be set up in the shaft and the lubrication of the shaft might be affected; on the other hand, if the fit is too tight or hard, the lubrication might fail, excessive frictional resistance might

be set up and undue heating thereby caused. If only one pair has to be made it may not matter what is exactly either the diameter of the shaft or the diameter of the bearing, so long as the required fit between the two is obtained. In other words, the shaft can be made to suit the bearing, or *vice versâ*.

When we come to manufacturing shafts and bearings on a large scale, however, we find that we cannot specially deal with each pair if the work is to be done economically. Hence, it is necessary to fix a standard for the bearings and one for the shafts, and to allow departures from these standards only up to certain limits. Thus, suppose that the nominal diameter of the shaft and bearing is 1 inch. This we can take to be the standard dimension for either the journal or the bearing, and fix the limits on the two sides of it, as, for example, 0·9995 inch and 1·0005 inch. If we adopt what is known as the "hole" basis, the nominal diameter becomes the standard diameter or bore of the bearing. In such a case the shaft must be smaller in diameter than the nominal diameter; and it must also be smaller than the lower limiting diameter of the bearing; that is, the diameter of the shaft must be less than 0·9995 inch. The standard for the shaft we can therefore take to be 0·9985 inch, and the two limits 0·9980 inch and 0·9990 inch. This would give us the fit required, and we should be quite certain that *every* shaft machined between these limits would fit *any* bearing machined between the other pair of limits.

In connection with this system there are several

terms in frequent use, the following being definitions of them.—

Tolerance is a permissible difference in the dimensions of work-pieces prescribed to allow for imperfections in workmanship, covering inaccuracies in machine tools, wear of cutting tools, and imperfect skill. In each of the above cases the tolerance, being the difference between the high and low limits, is equal to 0·001 inch

Allowance is the difference between the standard or nominal dimensions of two fitting parts or elements prescribed for the purpose of obtaining a certain kind of fit. There are four kinds of fits, namely, force fit, driving fit, sliding, keying or push fit, and running fit. In the above case, the allowance is (1·0000 – 0·9985) 0·0015 inch.

A force fit is of such a nature that the shaft has to be forced into the hole by the application of great pressure, or the part containing the hole has to be shrunk on the shaft.

In the case of a *driving fit*, the two engaging elements can be driven together or apart by the application of a small force delivered through the medium of a hand hammer.

A sliding or keying fit is the fit between two parts which have to slide relatively to one another. No great force ordinarily is required to push one part over or on the other.

A running fit is of such nature that one of the engaging parts can be revolved inside or on the other. There are three grades of this fit, the finest of the three grades being required in the case of shafts which have to revolve at high speeds.

Gauging Work-pieces.—This, in the interchangeable system of manufacture, is usually done by means of limit gauges already described in the first volume, there being a gauge for each of the two limiting dimensions. In the case of external gauging, the high-limit gauge must go on or over, whilst the low-limit gauge must not; in the case of internal gauging, the high-limit gauge must not go in or through, whilst the low-limit gauge must. Gauges, however, cannot be made to so-called *dead* dimensions, but are themselves made within certain limits, the tolerance in this case ranging from 5 to 10 per cent of the tolerance adopted in connection with the machining operations on the parts to be gauged.

APPENDIX.

TABLE I.—LIST OF DECIMAL EQUIVALENTS OF STUB'S STEEL WIRE AND DRILL GAUGE SIZES.

Gauge No.	Decimal Equivalent.	Gauge No.	Decimal Equivalent	Gauge No.	Decimal Equivalent	Gauge Letter.	Decimal Equivalent.
—	—						
	inch.		inch.		inch.		inch.
80	0·0130	53	0·0595	26	0·1470	A	0·2340
79	0·0140	52	0·0635	25	0·1495	B	0·2380
78	0·0150	51	0·0670	24	0 1520	C	0·2420
77	0·0160	50	0·0700	23	0·1540	D	0·2460
76	0·0180	49	0·0730	22	0·1570	E	0·2500
75	0·0200	48	0·0760	21	0·1590	F	0·2570
74	0·0220	47	0·0785	20	0 1610	G	0·2610
73	0·0230	46	0·0810	19	0 1660	H	0·2660
72	0·0240	45	0·0820	18	0 1695	I	0 2720
71	0·0260	44	0·0860	17	0·1730	J	0·2770
70	0·0270	43	0 0890	16	0·1770	K	0·2810
69	0·0290	42	0·0935	15	0·1800	L	0·2900
68	0·0300	41	0·0960	14	0·1820	M	0·2950
67	0·0310	40	0·0980	13	0·1850	N	0·3020
66	0·0320	39	0·0995	12	0·1890	O	0·3160
65	0·0330	38	0·1015	11	0·1910	P	0·3230
64	0·0350	37	0·1040	10	0·1935	Q	0 3320
63	0·0360	36	0·1065	9	0·1960	R	0·3390
62	0·0370	35	0·1100	8	0·1990	S	0·3480
61	0·0380	34	0·1110	7	0·2010	T	0·3580
60	0·0400	33	0·1130	6	0·2040	U	0·3680
59	0·0410	32	0·1160	5	0·2055	V	0·3770
58	0·0420	31	0·1200	4	0·2090	W	0·3860
57	0·0430	30	0·1285	3	0·2130	X	0·3970
56	0·0465	29	0·1360	2	0·2210	Y	0·4040
55	0·0520	28	0·1405	1	0·2280	Z	0·4130
54	0·0550	27	0·1440	—	—	—	—

TABLE II.—ANGULAR DRILLING SPEEDS AND FEEDS FOR PLAIN-CARBON STEEL TWIST DRILLS OF DIFFERENT DIAMETERS.

Diameter of Drill in Inches	On Steel and Iron.		On Brass and Bronze.	
	Angular Speed: Revs. per Min.	Linear Feed: Ins. per Rev.	Angular Speed: Revs. per Min.	Linear Feed: Ins. per Rev.
$\frac{1}{16}$	1250	0·003	1550	0·004
$\frac{1}{8}$	620	0·004	790	0·004
$\frac{3}{16}$	420	0·004	530	0·005
$\frac{1}{4}$	310	0·005	420	0·005
$\frac{5}{16}$	250	0·005	330	0·006
$\frac{3}{8}$	210	0·006	285	0·006
$\frac{7}{16}$	180	0·006	255	0·007
$\frac{1}{2}$	154	0·007	230	0·007
$\frac{9}{16}$	140	0·007	210	0·008
$\frac{5}{8}$	125	0·008	185	0·008
$\frac{11}{16}$	114	0·008	170	0·009
$\frac{3}{4}$	105	0·009	157	0·009
$\frac{13}{16}$	96	0·009	144	0·010
$\frac{7}{8}$	90	0·010	135	0·010
$\frac{15}{16}$	83	0·010	124	0·011
1	77	0·011	115	0·011
$1\frac{1}{8}$	70	0·011	105	0·012
$1\frac{1}{4}$	62	0·012	93	0·012
$1\frac{3}{8}$	57	0·012	85	0·013
$1\frac{1}{2}$	52	0·013	78	0·013
$1\frac{5}{8}$	48	0·013	72	0·014
$1\frac{3}{4}$	45	0·014	67	0·015
$1\frac{7}{8}$	41	0·015	61	0·016
2	38	0·016	57	0·017
$2\frac{1}{4}$	35	0·017	51	0·018
$2\frac{1}{2}$	31	0·018	46	0·019
$2\frac{3}{4}$	28	0·019	42	0·020
3	25	0·020	38	0·021

TABLE III.—ANGULAR DRILLING SPEEDS AND FEEDS FOR HIGH-SPEED TWIST DRILLS OF DIFFERENT DIAMETERS.

Diameter of Drill in Inches	On Steel and Iron.		On Brass and Bronze	
	Angular Speed: Revs. per Min	Linear Feed: Inches per Rev.	Angular Speed: Revs. per Min.	Linear Feed: Inches per Rev.
$\frac{1}{16}$	4000	0·004	4000	0·004
$\frac{1}{8}$	2000	0·005	3000	0·005
$\frac{3}{16}$	1300	0·006	1900	0·006
$\frac{1}{4}$	1000	0·007	1400	0·007
$\frac{5}{16}$	800	0·008	1100	0·008
$\frac{3}{8}$	650	0·009	950	0·009
$\frac{7}{16}$	570	0·010	800	0·010
$\frac{1}{2}$	500	0·011	700	0·011
$\frac{9}{16}$	440	0·012	620	0·012
$\frac{5}{8}$	400	0·013	560	0·013
$\frac{11}{16}$	360	0·014	510	0·014
$\frac{3}{4}$	330	0·015	470	0·015
$\frac{13}{16}$	310	0·016	430	0·016
$\frac{7}{8}$	290	0·017	400	0·017
$\frac{15}{16}$	270	0·018	375	0·018
1	250	0·019	350	0·019
$1\frac{1}{8}$	220	0·020	320	0·020
$1\frac{1}{4}$	200	0·021	285	0·021
$1\frac{3}{8}$	180	0·022	255	0·022
$1\frac{1}{2}$	165	0·023	235	0·023
$1\frac{5}{8}$	155	0·024	215	0·024
$1\frac{3}{4}$	145	0·025	200	0·025
$1\frac{7}{8}$	135	0·026	185	0·026
2	125	0·027	175	0·027
$2\frac{1}{4}$	110	0·028	160	0·028
$2\frac{1}{2}$	100	0·029	145	0·029
$2\frac{3}{4}$	91	0·030	130	0·030
3	83	0·030	115	0·030

TABLE IV.—INDEXING TABLE: SIMPLE INDIRECT METHOD.

Number of Divisions.	Number of Holes in Indexing-plate Circle.	Number of Turns of Indexing Handle.	Number of Divisions.	Number of Holes in Indexing-plate Circle.	Number of Turns of Indexing Handle.
2	any	20	36	27	$1\frac{3}{27}$
3	21	$13\frac{7}{21}$	37	37	$1\frac{3}{37}$
4	any	10	38	19	$1\frac{1}{19}$
5	,,	8	39	39	$1\frac{1}{39}$
6	21	$6\frac{14}{21}$	40	any	1
7	49	$5\frac{35}{49}$	41	41	$\frac{40}{41}$
8	any	5	42	21	$\frac{20}{21}$
9	27	$4\frac{12}{27}$	43	43	$\frac{40}{43}$
10	any	4	44	33	$\frac{30}{33}$
11	33	$3\frac{21}{33}$	45	27	$\frac{24}{27}$
12	21	$3\frac{7}{21}$	46	23	$\frac{20}{23}$
13	39	$3\frac{3}{39}$	47	47	$\frac{40}{47}$
14	49	$2\frac{42}{49}$	48	36	$\frac{30}{36}$
15	21	$2\frac{14}{21}$	49	49	$\frac{40}{49}$
16	32	$2\frac{16}{32}$	50	20	$\frac{16}{20}$
17	34	$2\frac{12}{34}$	52	39	$\frac{30}{39}$
18	27	$2\frac{6}{27}$	54	27	$\frac{20}{27}$
19	19	$2\frac{2}{19}$	55	33	$\frac{24}{33}$
20	any	2	56	49	$\frac{35}{49}$
21	21	$1\frac{19}{21}$	58	29	$\frac{20}{29}$
22	33	$1\frac{27}{33}$	60	30	$\frac{20}{30}$
23	23	$1\frac{17}{23}$	62	31	$\frac{20}{31}$
24	39	$1\frac{26}{39}$	64	32	$\frac{20}{32}$
25	20	$1\frac{12}{20}$	65	39	$\frac{24}{39}$
26	39	$1\frac{21}{39}$	66	33	$\frac{20}{33}$
27	27	$1\frac{13}{27}$	68	34	$\frac{20}{34}$
28	49	$1\frac{21}{49}$	70	21	$\frac{12}{21}$
29	29	$1\frac{11}{29}$	72	27	$\frac{15}{27}$
30	39	$1\frac{13}{39}$	74	37	$\frac{20}{37}$
31	31	$1\frac{9}{31}$	75	30	$\frac{16}{30}$
32	20	$1\frac{6}{20}$	76	19	$\frac{10}{19}$
33	33	$1\frac{7}{33}$	78	39	$\frac{20}{39}$
34	34	$1\frac{6}{34}$	80	30	$\frac{15}{30}$
35	49	$1\frac{7}{49}$	82	41	$\frac{20}{41}$

TABLE IV.—INDEXING TABLE. SIMPLE INDIRECT METHOD (*continued*).

Number of Divisions	Number of Holes in Indexing-plate Circle.	Number of Turns of Indexing Handle.	Number of Divisions.	Number of Holes in Indexing-plate Circle	Number of Turns of Indexing Handle.
84	21	$\frac{10}{21}$	165	33	$\frac{8}{33}$
85	34	$\frac{16}{34}$	168	21	$\frac{5}{21}$
86	43	$\frac{20}{43}$	170	34	$\frac{8}{34}$
88	33	$\frac{15}{33}$	172	43	$\frac{10}{43}$
90	27	$\frac{12}{27}$	180	27	$\frac{6}{27}$
92	23	$\frac{10}{23}$	184	23	$\frac{5}{23}$
94	47	$\frac{20}{47}$	185	37	$\frac{8}{37}$
95	19	$\frac{8}{19}$	188	47	$\frac{10}{47}$
96	36	$\frac{15}{36}$	190	19	$\frac{4}{19}$
98	49	$\frac{20}{49}$	195	39	$\frac{8}{39}$
100	20	$\frac{8}{20}$	196	49	$\frac{10}{49}$
104	39	$\frac{15}{39}$	200	20	$\frac{4}{20}$
105	21	$\frac{8}{21}$	205	41	$\frac{8}{41}$
108	27	$\frac{10}{27}$	210	21	$\frac{4}{21}$
110	33	$\frac{12}{33}$	215	43	$\frac{8}{43}$
115	23	$\frac{8}{23}$	216	27	$\frac{5}{27}$
116	29	$\frac{10}{29}$	220	33	$\frac{6}{33}$
120	21	$\frac{7}{21}$	230	23	$\frac{4}{23}$
124	31	$\frac{10}{31}$	232	29	$\frac{5}{29}$
128	32	$\frac{10}{32}$	235	47	$\frac{8}{47}$
130	39	$\frac{12}{39}$	240	36	$\frac{6}{36}$
132	33	$\frac{10}{33}$	245	49	$\frac{8}{49}$
135	27	$\frac{8}{27}$	248	31	$\frac{5}{31}$
136	34	$\frac{10}{34}$	260	39	$\frac{6}{39}$
140	21	$\frac{6}{21}$	264	33	$\frac{5}{33}$
144	36	$\frac{10}{36}$	270	27	$\frac{4}{27}$
145	29	$\frac{8}{29}$	272	34	$\frac{5}{34}$
148	37	$\frac{10}{37}$	280	49	$\frac{7}{49}$
150	30	$\frac{8}{30}$	290	29	$\frac{4}{29}$
152	19	$\frac{5}{19}$	296	37	$\frac{5}{37}$
155	31	$\frac{8}{31}$	300	30	$\frac{4}{30}$
156	39	$\frac{10}{39}$	310	31	$\frac{4}{31}$
160	32	$\frac{8}{32}$	312	39	$\frac{5}{39}$
164	41	$\frac{10}{41}$	320	32	$\frac{4}{32}$

TABLE V.—HELIX ANGLES FOR VARIOUS RATIOS OF LEAD OF HELIX TO DIAMETER OF PITCH CYLINDER.

Lead / Diameter.	Helix Angle.		Lead / Diameter.	Helix Angle.		Lead / Diameter.	Helix Angle.	
	Degs.	Mins.		Degs.	Mins.		Degs.	Mins.
1·00	72	21	4·30	36	9	9·75	17	52
1·10	70	42	4·40	35	30	10·00	17	27
1·20	69	7	4·50	34	54	10·25	17	1
1·30	67	33	4·60	34	19	10·50	16	39
1·40	65	0	4·70	33	45	10·75	16	17
1·50	64	32	4·80	33	12	11·00	15	56
1·60	63	4	4·90	32	40	11·50	15	17
1·70	61	37	5·00	32	8	12·00	14	40
1·80	60	12	5·10	31	38	12·50	14	7
1·90	58	51	5·20	31	8	13·00	13	38
2·00	57	31	5·30	30	39	13·50	13	8
2·10	56	15	5·40	30	11	14·00	12	39
2·20	55	0	5·50	29	44	15·00	11	50
2·30	53	48	5·60	29	18	16·00	11	6
2·40	52	37	5·70	28	52	17·00	10	28
2·50	51	30	5·80	28	27	18·00	9	54
2·60	50	23	5·90	28	2	19·00	9	23
2·70	49	19	6·00	27	38	20·00	8	56
2·80	48	16	6·20	26	52	25·00	7	10
2·90	47	16	6·40	26	9	30·00	5	59
3·00	46	19	6·60	25	27	35·00	5	7
3·10	45	23	6·80	24	48	40·00	4	29
3·20	44	28	7·00	24	10	50·00	3	36
3·30	43	35	7·25	23	26	60·00	3	0
3·40	42	44	7·50	22	44	70·00	2	34
3·50	41	54	7·75	22	4	80·00	2	15
3·60	41	7	8·00	21	26	90·00	2	0
3·70	40	21	8·25	20	51	100·00	1	48
3·80	39	35	8·50	20	17	120·00	1	30
3·90	38	52	8·75	19	45	140·00	1	17
4·00	38	10	9·00	19	15	160·00	1	7
4·10	37	29	9·25	18	46	180·00	1	0
4·20	36	48	9·50	18	18	200·00	0	54

TABLE VI.—LIST OF WHOLE DEPTHS OF TOOTH SPACES FOR VARIOUS DIAMETRAL PITCHES OF TOOTHED GEAR-WHEELS.

Diametral Pitch.	Addendum.	Root Clearance	Dedendum.	Whole Depth.
1	1·0000	0·1571	1·1571	2·1571
1¼	0·8000	0·1257	0·9257	1·7257
1½	0·6667	0·1047	0·7714	1·4381
1¾	0·5714	0·0898	0·6612	1·2326
2	0·5000	0·0785	0·5785	1·0785
2¼	0·4444	0·0698	0·5142	0·9586
2½	0 4000	0·0628	0·4628	0·8628
2¾	0·3636	0 0572	0·4208	0·7844
3	0·3333	0·0524	0·3857	0·7190
3½	0·2857	0 0449	0·3306	0·6163
4	0·2500	0·0393	0·2893	0·5393
5	0·2000	0·0314	0·2314	0·4314
6	0 1667	0·0262	0·1929	0·3595
7	0·1429	0·0224	0·1653	0·3082
8	0·1250	0 0196	0·1446	0·2696
9	0·1111	0 0175	0·1285	0·2396
10	0·1000	0·0157	0·1157	0·2157
11	0·0909	0·0143	0·1052	0·1961
12	0·0833	0 0132	0·0965	0·1798
13	0·0769	0·0121	0·0890	0·1659
14	0 0714	0·0112	0 0826	0·1540
15	0 0667	0·0105	0·0772	0·1439
16	0·0625	0·0098	0 0723	0·1348
17	0·0588	0·0092	0·0680	0·1268
18	0·0556	0·0087	0·0642	0·1198
19	0·0526	0·0082	0·0608	0·1134
20	0·05 0	0·0078	0 0578	0·1078
21	0·0476	0·0075	0·0551	0·1027
22	0·0454	0·0072	0·0526	0·0980
23	0·0434	0·0068	0·0502	0·0936
24	0·0417	0 0065	0·0482	0·0899
26	0·0385	0·0060	0·0445	0·0830
28	0·0357	0·0056	0·0413	0·0770
30	0·0333	0·0052	0·0385	0·0718
32	0·0313	0 0049	0·0362	0·0675

TABLE VII.—LIST OF TAPERS.

Taper . 1 in.	Taper per Foot: Inches.	Total or Included Angle (ϕ).		Side Angle (θ)		Cos θ.
		Degs.	Mins.	Degs.	Mins.	
192·0	$\frac{1}{16}$	0	18	0	9	1·00000
96·0	$\frac{1}{8}$	0	36	0	18	0·99999
64·0	$\frac{3}{16}$	0	54	0	27	0·99997
48·0	$\frac{1}{4}$	1	12	0	36	0·99995
38·4	$\frac{5}{16}$	1	30	0	45	0·99991
32·0	$\frac{3}{8}$	1	47	0	54	0·99988
27·4	$\frac{7}{16}$	2	5	1	3	0·99983
24·0	$\frac{1}{2}$	2	23	1	12	0·99978
21·3	$\frac{9}{16}$	2	41	1	21	0·99972
19·2	$\frac{5}{8}$	3	0	1	30	0·99966
17·5	$\frac{11}{16}$	3	17	1	38	0·99959
16·0	$\frac{3}{4}$	3	35	1	48	0·99951
14·8	$\frac{13}{16}$	3	53	1	56	0·99943
13·7	$\frac{7}{8}$	4	10	2	5	0·99934
12·8	$\frac{15}{16}$	4	28	2	14	0·99924
12·0	1	4	46	2	23	0·99913
9·2	$1\frac{1}{4}$	5	58	2	59	0·99864
8·0	$1\frac{1}{2}$	7	9	3	35	0·99804
6·9	$1\frac{3}{4}$	8	20	4	10	0·99736
6·0	2	9	31	4	46	0·99654
5·3	$2\frac{1}{4}$	10	43	5	21	0·99564
4·8	$2\frac{1}{2}$	11	54	5	57	0·99461
4·4	$2\frac{3}{4}$	13	4	6	32	0·99351
4·0	3	14	15	7	8	0·99226
3·4	$3\frac{1}{2}$	16	36	8	18	0·98953
3·0	4	18	55	9	27	0·98643
2·7	$4\frac{1}{2}$	21	14	10	37	0·98288
2·4	5	23	32	11	46	0·97899
2·2	$5\frac{1}{2}$	25	49	12	54	0·97476
2·0	6	28	4	14	2	0·97015
1·7	7	32	31	16	16	0·95997
1·5	8	36	52	18	26	0·94869
1·3	9	41	7	20	34	0·93626
1·2	10	45	14	22	37	0·92310
1·1	11	49	15	24	38	0·90899
1·0	12	53	8	26	34	0·89441

TABLE VIII.—ANGULAR SPEEDS, IN R.P.M., CORRESPONDING TO DIFFERENT SURFACE CUTTING SPEEDS AND DIAMETERS OF WORK-PIECES OR CUTTING TOOLS.

Diameter of Work-piece or Cutting Tool.		Surface Cutting Speed, in Feet per Minute.						
		20.	30.	40.	50.	60	80	100.
Ft.	Ins.							
0	0¼	305	458	611	764	917	1222	1528
0	0½	153	229	305	382	458	611	764
0	1	76	115	153	191	229	305	382
0	1½	51	76	102	127	153	204	255
0	2	38	57	76	96	114	153	191
0	2½	31	45	61	76	92	122	153
0	3	25	38	51	64	76	102	127
0	3½	22	33	43	55	65	87	109
0	4	19	28	38	48	57	76	96
0	4½	17	25	34	42	51	68	85
0	5	15	23	31	38	46	61	76
0	5½	14	21	28	35	42	56	70
0	6	13	19	25	32	38	51	64
0	7	11	16	22	27	33	44	55
0	7½	10	15	20	25	31	40	51
0	8	9·5	14	19	24	29	38	48
0	9	8·5	13	17	21	25	34	42
0	10	8·0	12	16	19	23	30	38
0	10½	7·3	11	15	18	22	29	36
0	11	6·9	10	14	17	21	28	35
1	0	6·4	9·5	13	16	19	25	32
1	2	5·7	8·2	11	14	16	22	27
1	4	4·8	7·2	9·5	12	14	19	24
1	6	4·2	6·4	8·5	11	13	17	21
1	8	3·8	5·7	7·6	9·6	11	15	19
1	10	3·5	5·2	6·9	8·7	10	14	17
2	0	3·2	4·8	6·4	8·0	9·5	13	16
2	6	2·5	3·8	5·1	6·4	7·6	10	13
3	0	2·1	3·2	4·2	5·3	6·4	8·5	11
3	6	1·8	2·7	3·6	4·5	5·4	7·3	9·1
4	0	1·6	2·4	3·2	4·0	4·8	6·4	8·0
4	6	1·4	2·1	2·8	3·5	4·2	5·7	7·1
5	0	1·2	1·9	2·5	3·2	3·8	5·1	6·4

TABLE IX.—DEGREES OF HARDNESS, OR GRADES OF GRINDING WHEELS.

Degree of Hardness.	Vitrified and Silicate Wheels.	Elastic and Vulcanite Wheels.
Extremely soft	A	—
" "	B	—
" "	C	—
Very soft	D	—
"	E	—
"	F	—
Soft	G	—
"	H	—
"	I	1
Medium soft	J	1½
" "	K	2
" "	L	2½
Medium	M	3
"	N	3½
"	O	4
"	P	5
Medium hard	Q	6
" "	R	—
" "	S	—
Hard	T	—
"	U	—
"	V	—
Very hard	W	—
"	X	—
"	Y	—
Extremely hard	Z	—

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